Experimental Investigation of novel heat pipe augmented solar wall with nanofluid

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Abstract: The heat pipe augmented solar wall operates much more efficiently for domestic air cooling than alternative passive solar technologies. The exceptionally high conductivity of heat pipes allows for much greater heat gains, and significantly reduces the response time of the unit. The response time is also reduced by a smaller thermal mass of preheating components, which allows the system to passively alternate between insulating and heating conditions much more quickly. The heat pipe augmented solar wall is a type of isolated gain system which greatly increases the insulation value of the solar cooling device with the advantage of the "thermal diode" phenomenon in heat transfer with heat pipes. These units perform similar to ground-based isolated gain collection units but can be installed in any solar-facing wall. The increased insulation value of these systems and their ability for installation in any building with solar exposure makes them much more likely to have the greatest impact on the building cooling market. With the development of nanotechnology, an innovative heat transfer fluid arises. Nanofluid, a relatively new class of fluids which consist of a base fluid with nano sized particles (1-100 nm) suspended within them. These particles are generally metals or metal oxides. Nanofluid have been considered as a new-type heat transfer fluid because of their substantial rise in liquid thermal conductivity, liquid viscosity, and heat transfer coefficient.

Keywords: Solar Wall, Heat pipe, nanofluid, LPH, Efficiency.

I. INTRODUCTION

Energy demand was drastically increased by the industrial revolution in the early 19th century. Before this event, gross domestic product was relatively stable for all nations and the energy demand per capita was very small. Requirements for comfortable working conditions have resulted in an increased demand for air conditioning, likely achieved through mechanical cooling systems consuming electricity as the principal source of energy. (C. Dharuman 2006)

Electricity usage of the active building cooling systems employed at present are sometimes substantially higher at relatively low cost of equipment, thereby making them financially appealing to the building sector. More solar energy strikes the earth's surface in an hour than the amount of energy consumed by the world population in a year. 0.15% of the surface area of the United States in solar panels would produce all of the nation's energy demand. Solar radiations are the huge source of energy which is available on earth surface and that solar energy Utilizing for maintaining the temperature of room. The primary purpose is to maintain the room temperature at a level of required comfort and secondary purpose is recovery of waste heat by heating any type of fluid. Another advantage of the solar augmented heat pipe is it does not require any external power source for its operation. (P.J. Boait, D. Dixon 2012)

The heat pipe augmented solar wall is a type of isolated gain system which greatly increases the insulation value of the solar heating device with the advantage of the "thermal diode" phenomenon in heat transfer with heat pipes. The system also eliminates the need for solar-facing slopes next to a residence in order to take advantage of a thermo syphon effect. These units perform similar to ground-based isolated gain collection units but can be installed in any solar-facing wall. The increased insulation value of these systems and their ability for installation in any building with solar exposure makes them much more likely to have the greatest impact on the building heating market. (X.Q. Zhai, R.Z. Wang 2007)

The proposed heat pipe system incorporates a heat pipe to transfer heat through an insulated wall from the solar absorber to the thermal mass. Heat pipes transfer heat in only one direction, similar to thermo syphons, but use a two-phase fluid that provides improved heat transfer and requires little elevation difference between the evaporator and condenser sections Liquid is boiled in the lower evaporator section of the heat pipe and the vapor rises to the upper condenser end, where the vapor condenses and transfer its energy. The condensate then falls by gravity back to the evaporator.(H. N. Chaudhry 2012)

II. HEAT PIPE OPERATION

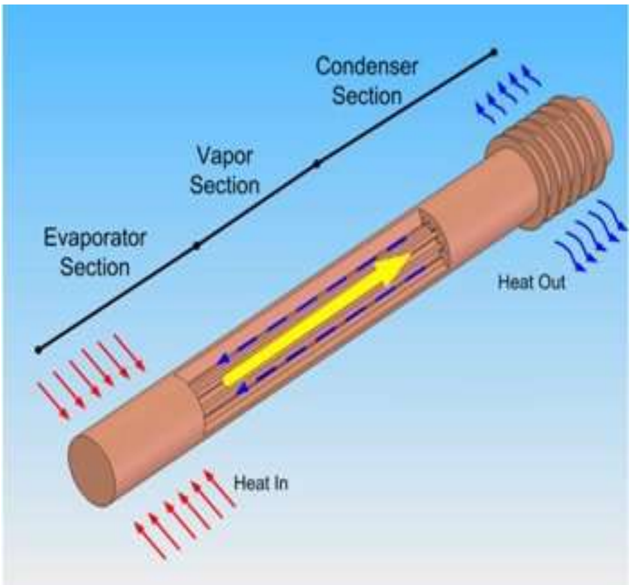

Fig.1 Heat Pipe Operation

Heat pipes are thermal transfer devices that involve an evaporator, condenser, and often an adiabatic section (vapor section in Fig 1). Heat pipes usually work at a vacuum, with a phase change fluid chosen according to the operating temperatures of the heat pipe. When heat is transferred into the evaporator section, the fluid is boiled. The vapor then rises or circulates to the condenser end of the heat pipe, where heat is lost due to the lower temperature at this location, and the vapour returns to its liquid state. The liquid is driven back to the evaporator section by gravity (in a gravity assisted heat pipe), inertia (in a rotating heat pipe), or by capillary action through a wicking structure (in wicking heat pipes). In a gravity assisted heat pipe (a heat pipe oriented at an angle), the lower end is the evaporator and the upper end is the condenser. When the evaporator end is hotter than the condenser, high thermal conductivity is achieved through circulation.

When the evaporator end is colder than the condenser, the fluid remains liquid in the evaporator section and does not circulate (fig 1). This leads to good thermal resistance to heat flow in the undesired direction, and is referred to as the thermal diode effect. Also, since energy is absorbed primarily as latent heat, the heat pipe operates with very small temperature gradients along its length. This leads to very high thermal conductance properties, and values 700 times greater than copper have been achieved. This thermal diode effect makes heat pipes very suitable for a solar application where the absorber and thermal mass need to be separated by an insulator to ensure minimal heat losses at night, but where maximum heat transfer from the absorber to the thermal mass are desired. (H.N.Chaudhry, B.R.Hughes, 2014)

III. PROBLEM DEFINITION

Within the exterior wall of light steel houses, an environmental control device can be placed that can “harvest” solar thermal energy. This device should effectively buffer the solar heat gain and even capture this heat energy and transfer it in such a way that it can be used. During summer, this device would be able to absorb the heat from the sun during the day so that this preserved heat could be transferred and utilized indoors and maintains indoor temperature, thus attempts can be made to develop an innovative wall heat collection prototype which maintains the indoor temperature and serves a device to collect heat based on the façade energy-harvesting concept.

This work aims to investigate experimentally the thermal performance of novel heat pipe augmented solar wall with nanofluid. Selection of nanofluid as working fluid in heat pipe improves thermal properties of working fluid of heat pipe and thus improves the performance. The collected heat can be utilized to heat water which intern maintains the ambient temperature within limits. It serves both purposes of collection of heat and at the same time isolate the indoor environment from surrounding. The thermal performance of the proposed prototype is to experimentally investigate the physical configuration under consideration and this study the operational performance assessment of heat pipe augmented solar wall with nanofluid under practical conditions.

IV. EXPERIMENTAL SETUP

An experimental model can be constructed to test the performance characteristics of the heat pipe augmented solar wall with nanofluid as working fluid. The design consisted of five individual heating units each consisting of an absorber plate clamped to a heat pipe. The heat pipes can be mounted at 5 degrees and consisted of an evaporator, adiabatic, and condenser section. The adiabatic section of the heat pipe can run through a layer of thermal insulation and then can be placed within a water tank which acted as a thermal mass. An aluminum frame can be built to support the absorbers, heat pipes, and water tanks, and the five heating units can be enclosed within an aluminum sheet metal skin with a glazing on the front of the unit. The rear of the unit consisted of a screen facing on the heated face which allowed the thermal mass to slowly give off heat to the space. Each of the five heating units can be designed to be as close to identical as possible. However, geometric efficiency and aesthetic considerations of the heat pipe system resulted in two of the five total heating units being designed with slight modifications. These modified heating units can be at the top and bottom of the model. Descriptions of the experimental model and its construction apply to all of the heating units, and modifications of the two heating units will be addressed when applicable. Fig 2 shows the designed heating units with heat pipes.

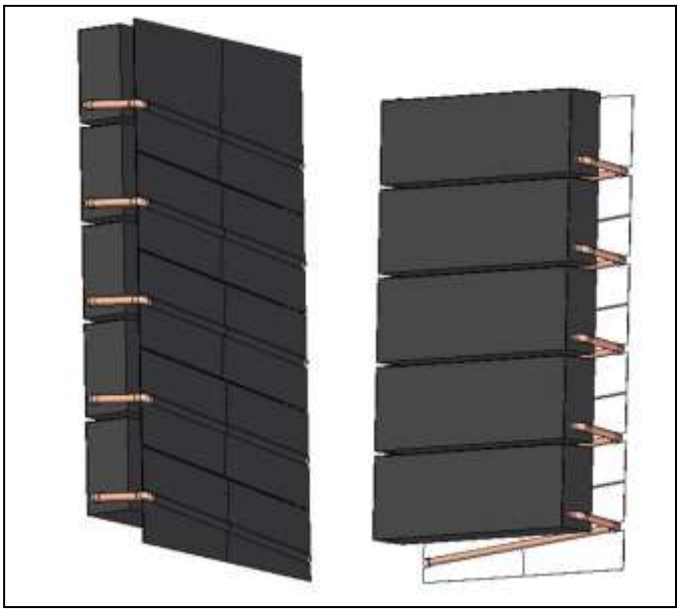

Fig.2 All Heating Units with Heat Pipes

The measuring instruments required to assess the performance of the heat pipe solar wall can be used. The temperature at the different points of the experimental set ups such as wall of heat pipe, heat pipe fin surface, cooling water inlet and outlet can be measured. The solar radiation can be measured with the help of solar radiation pyranometer. The variation indoor temperature can be measured during the testing procedure with and without the heat pipe augmented solar wall unit.

V. DESIGN OF SETUP

5.1 Dimensioning Heat Pipe Section

The circulation tubes can also be used as structural support for the curtain wall; therefore, the tube material used in this study is copper. The joints between the circulation tube and square duct were constructed with filet material, and the tubes were shaped to maintain a constant cross-sectional area throughout the circulation loop.

The outer diameter of the tube can be 16 mm. The inner diameter is 12mm, and the wall thickness is 2 mm (fig 3). To align the loop with the exterior wall, we fixed the horizontal distance to be approximately 200 mm to match the typical wall thickness. Therefore, the overall exterior size of the test cell can be 40 cm wide, 20 cm deep, and 70 cm high, which matches the dimensions of typical metal curtain walls. The cooling section is opposite the heated section. For experimentation purpose set up is designed with various aspects. Fig 3 shows the layout of experimental set up.

5.2 Test cell

The experimental test cell consisted of an exterior wall plate, a vertical flow duct with a square cross section, a circulation loop, and a cooling sleeve. The exterior wall width was 40 cm and the height was 80 cm, which is a commonly used curtain wall height. On one side of the wall, incident solar radiation used to heat the wall surface, simulating the solar radiation received by the exterior wall plate ,on the other side (inside the curtain wall), the vertical flow duct measured 30 mm wide by 20 mm high and can be welded specifically to form a heat exchanger.

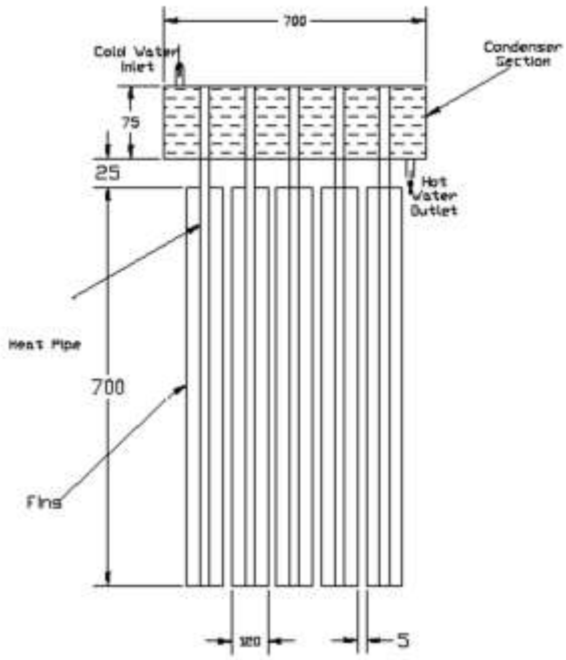

Fig.3 Layout of Experimental Setup

5.3 Cooling sleeve

This section includes a cylindrical cooling sleeve made of aluminum. In addition, the cooled section uses water from a thermally regulated bath to extract heat from the loop. The cooling sleeve measured 61 mm × 300 mm and had internal dimensions of40 mm × 280 mm.

5.4 Insulation over cooling sleeve

Cotton was wrapped around the cooled section and the exterior of the circulation tube as insulation to reduce heat losses from the system.

5.5 Temperature sensors with indicator

RTD (PT-100) sensors are used at various points around the loop to measure the water and wall temperatures. In addition, resistance temperature detectors (RTDs) are used at the cooling water entrance and exit. The maximum temperature occurred in the proposed system is expected to be 75 ^{0}C hence it has been decided to select the RTD (PT-100) sensors having range up to 150^{0}Cwith a resolution of ±0.1^{0}C.

5.6 Pyranometer

It is used to measure the intensity of solar radiations incident on the curtain wall with the help of pyranometer. As the pyranometer cost is high and it has been decided to conduct the trial in the premises of Central Radiation Laboratory, Pashan where the radiation Pyranometer is available.

5.7 Calibrated measuring flasks/ Rotameter

A flow meter can be used to measure the flow rate of the cooling water entering and exiting the thermally regulated bath. The average flow rates tested were 35, 20, and 10 mL/s. In case the rotameter with this lower capacity is not available then it has been decided to measure the controlled mass flow rate of water with the help of the calibrated measuring flask.

5.8 Flow Control valve

It is used to control the mass flow rate of water entering cooling sleeve. The flow control valve compatible with the circulating loop can be selected.

5.8 Preparation of nanofluid

Nanofluid is prepared by two step method. The copper oxide nanoparticles having average size 50 nm is directly purchased from USA based company Nanoshell. In this study water is used as a base fluid for copper oxide. Volume of Nanofluid used is 50% of total volume all heat pipes. Calculated mass of nanoparticles is inserted in distilled water which is followed by stirring and then sonication process is performed for 1 hour. Copper oxide nanofluid of 1% & 2% volumetric concentration is prepared in the laboratory. Fig 4 shows the nanofluid preparation apparatus.

Fig.4 Nanofluid preparation apparatus

VI. EXPERIMENTAL STRATEGY

This system contains analyzing the performance of heat pipe solar wall with nanofluid. Hence the major component of the system is heat pipe with nanofluid. Experimentation is carriesd out with conventional building wall, heat pipe augmented solar wall with water and heat pipe augmented solar wall with nanofluid. The observation for these all comparator is taken as time from morning 9am to 5pm at the same time measuring the intensity of radiation w/m^2, atmospheric temperature ^{0}C and different temperature taken for the same time. Average cabinet temperature record at 2.5 LPH, 5 LPH, 7.5 LPH & 10 LPH flow of fluid.

VII. RESULTS AND DISCUSSION

S1

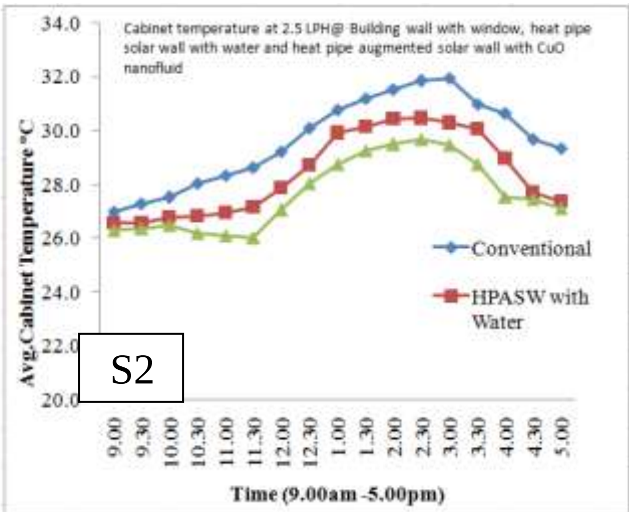

Fig.5 Avg. cabinet temperature vs time @ 2.5LPH

The experiment was perform to know the cabinet temperature by using heat pipe solar wall with copper oxide nanofluid and compare the results with conventional building wall and heat pipe solar wall with water by changing the flow rate. Also efficiency of heat pipe solar wall is compared with the conventional building window and heat pipe solar wall with water.

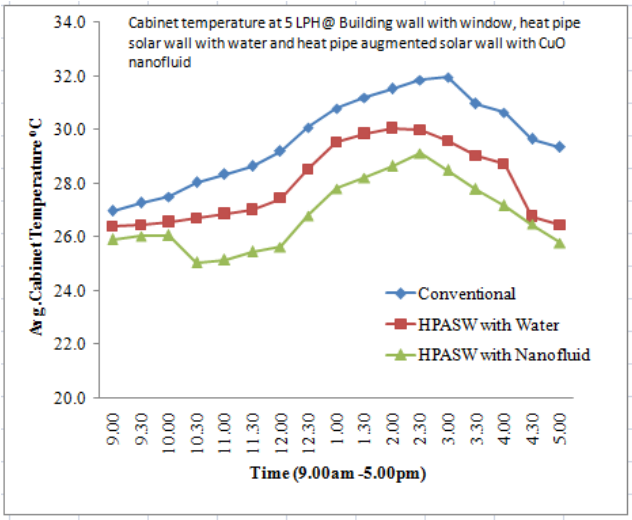

Fig.6 Avg. cabinet temperature vs time @ 5LPH

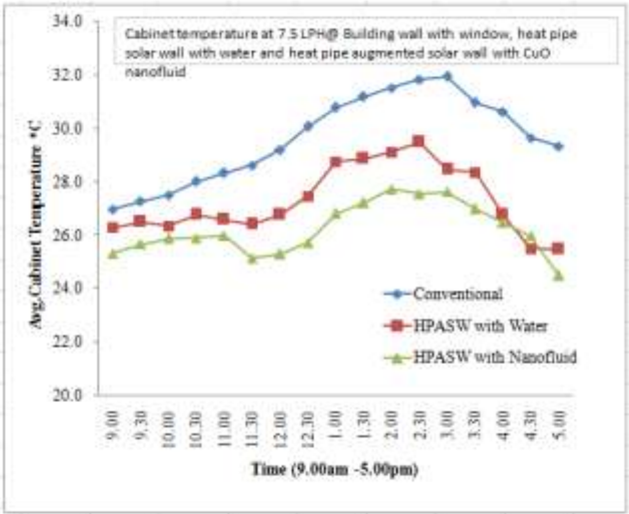

Fig.7 Avg. cabinet temperature vs time @ 7.5LPH

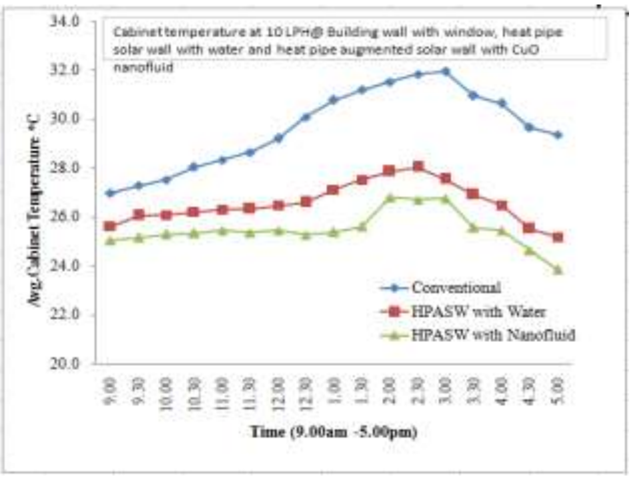

Fig.8 Avg. cabinet temperature vs time @ 10LPH

The following results shows the instantaneous collector efficiency with respect to time @2.5LPH, 5LPH, 7.5LPH, 10LPH. The comparison of efficiency with water and CuO nanofluid which shows better by using CuO nanofluid.

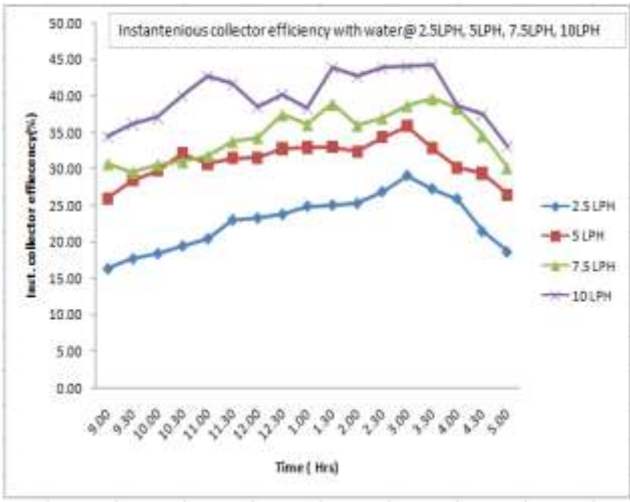

Fig.9 Inst. collector efficiency vs time @ 2.5, 5, 7.5, 10LPH with water

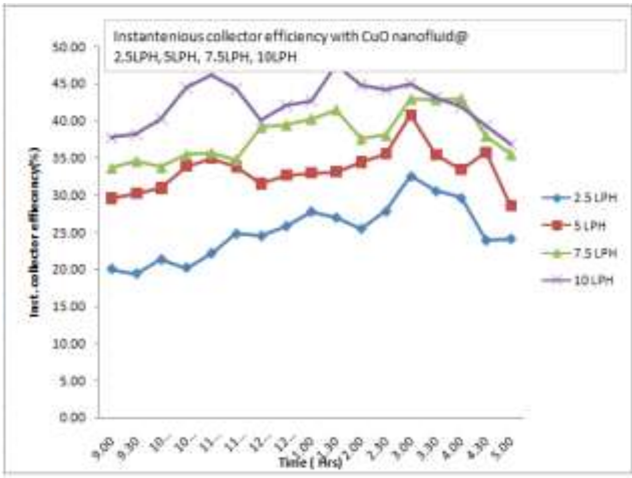

Fig.10 Inst. collector efficiency vs time @ 2.5, 5, 7.5, 10LPH with CuO nanofluid

Intensity of solar radiation(W/m2) with respect to time with water and CuO@ 2.5LPH, 5LPH, 7.5LPH, 10LPH shows following results.

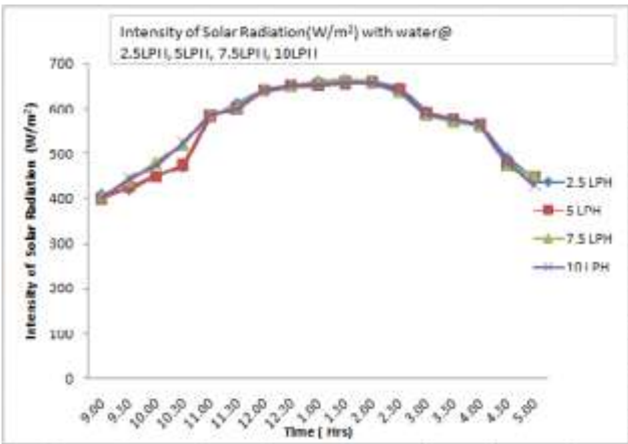

Fig.11 Intensity of solar radiation vs time @ 2.5, 5, 7.5, 10LPH with water

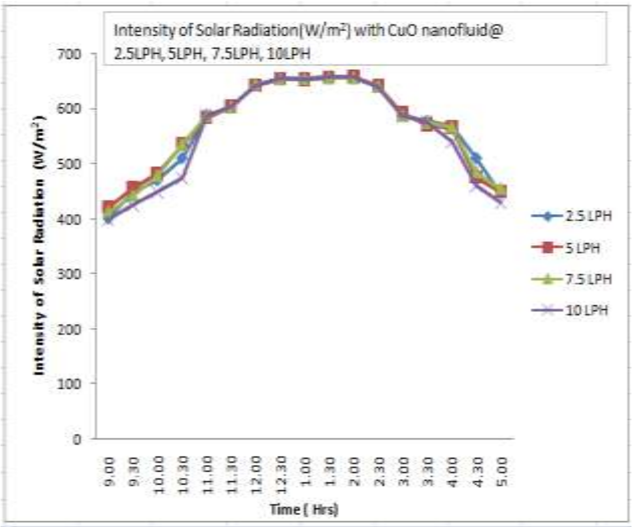

Fig.12 Intensity of solar radiation vs time @ 2.5, 5, 7.5& 10LPH with CuO nanofluid

VIII. CONCLUSION

Solar radiations are the huge source of energy which is available on earth surface. In this we using the solar energy for maintaining the temperature of room. In this case the primary purpose is to maintain the room temperature at a level of required comfort and secondary purpose is recovery of waste heat by heating any type of fluid. Another advantage of the solar augmented heat pipe is it does not require any external power source for its operation. Also this system does not have any moving parts, hence the operation is friction less. With the use of nanofluids in heat pipe there is increase in the rate of heat transfer. As compare to conventional system, this system has low running and maintenance cost.

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