Thermal Energy Storage System Integrated with Heat Pipe for Concentrated Solar Applications

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ABSTRACT

A system is devised to store the thermal energy of solar radiation in a phase change material by enhancing the heat transfer rate with the help of heat pipes. The system consists of a parabolic trough collector, a number of heat pipes, a container filled with phase change material, copper tubes wounding the container, pipes, valves etc. Solar energy is concentrated to the evaporator side of heat pipes by the parabolic trough collector and the energy is carried to the phase change material which surrounds the condenser side of heat pipe. The stored energy can be utilized by passing water through copper tubes wraps around the container. Experiments are conducted in sunny days of April under real time conditions. Results showed that the system could effectively store thermal energy during day time. The efficiency of the system is found to be 34.5% which is comparable to any solar thermal system.

KEY WORDS*:* Concentrated Solar Power, Parabolic Trough Collector, heat pipe, Latent energy storage.

1. INTRODUCTION

Solar energy is one of the most abundant renewable sources of energy which in recent times has come under a lot of consideration and a great amount of research has been done on this area. The main obstacles with development of solar energy technology are its nature of intermittency and diffusivity. The problems associated with low energy density of solar energy can be overcome by using different concentrating technics. Concentrated Solar Power (CSP) is one of the key areas of improving solar efficiency by reducing the area and maximizing the amount of radiation by concentrating it over a small area. CSP has found applications in many areas like power generation, solar refrigeration, solar cooking etc. CSP has to get more attention as it is more economic and has less environmental impact compared to other solar energy harnessing technics (Desideri, 2013). A comparison was made between CSP and Concentrated Photo Voltaic (CPV), by Desideri (2013). The comparison was made on two grounds where in both the systems have the same amount of area and the other where they are supplied with same nominal power. The main focus was on getting maximum energy output with these constraints under consideration. Results indicated that energy outputs received from CPV system were pretty high at the initial stage but the amount of power generation decreased with time. Whereas results obtained from CSP system showed a stable and consistent generation of power throughout the period. Cumulative power production with the same amount of area indicates that the rate of power generation has been on an increase in both systems which is nearly the same. Cumulative power production with same nominal power supplied suggests that the rate of power generation in case of CPV system is better than that of CSP system. Omar (2015), studied about the structure and working of the parabolic reflector. A typical PTC system consists of an optical concentrator, a tubular thermal receiver, a steam generation cycle, a tracking mechanism, and an optional thermal storage system. The problem of intermittency in availability of solar radiation should be met with different thermal energy storage systems, where the energy associated with the solar radiation is stored during day time and release out energy during night time. Belen Zalba (2003), compared different options for latent thermal energy storage based on the melting point and other properties like heat of fusion, density and thermal conductivity of various materials and suggested paraffin wax as material for latent energy storage in low and medium temperature applications.

Heat pipes have a varied amount of application in the field of solar energy which has not been completely utilized and can be explored further. Heat pipe technology has come into picture in recent times mainly because it can transfer heat over considerable distance without any losses and also it has no moving parts associated with it which helps in reducing maintenance. According to Saffa Riffat (2007), heat pipe technology has developed rapidly. In recent years, many new types of heat pipe with innovative structure/shape, wick and working fluids have been reported. The high heat transfer efficiency of heat pipes has led to their development in many applications, including solar energy systems, heat recovery systems, air conditioning systems, cooling of energy storage and electronic equipment, industrial applications and space apparatus. Liang Zang (2012), made a study on a U- type natural circulation heat pipe by placing it at the focus of the PTC. The heat pipe is connected to a boiler, charging and discharging tube and water is made to pass as the heat transfer fluid which is getting converted to steam. Thermal characteristics were studied at various pressures and time of interval during daytime. Observation suggest that system can generate steam of pressure up to 0.75 MPa and Thermal efficiency achieved was about 38%. Also thermal resistance of heat pipe changes with heat power.

Table.1. Properties of Paraffin Wax

Description	Value
Melting Point	48-65°C(55°C)
Density	900kg/m^3
Specific Heat	2.2 kJ/kg-K
Latent Heat of Fusion	210 kJ/kg

2. EXPERIMENTAL

System Description: The set up includes a parabolic trough collector (PTC), heat pipe filled with working fluid a storage tank filled with some thermal energy storage materials like paraffin wax, copper tube which wraps the container, supporting structures etc. PTC will concentrate solar radiation into its focal line, where the heat pipe is placed. The heat pipes are enclosed in a borosilicate glass tube, which is evacuated with the heat pipes being painted black so as to maximize the thermal absorptivity. The other end of heat pipe is immersed in the storage tank and is surrounded by some energy storage materials. The evaporator end of heat pipe will be getting heated up and the energy will be dissipated to the storage material. Metallic fins are provided at the condenser end of heat pipe so as to maximize the heat dissipation to the phase change material. Thermocouples can be fixed at different points of the fin at specified distance from heat pipe surface, in condenser section, to give the temperature distribution in the storage material. The thermal energy storage material used is paraffin wax which has been selected because of its melting temperature range. A copper coil is wound over the PCM container, which is completely insulated using an asbestos rope.

Setup Dimensions:

Parabolic Trough Collector:

- Equation of parabola ; $Y = 0.0583x^2 - 1.4549x + 9.1495$
- Focus = (0.12,0.04), taking vertex as origin
- aperture area = =0.23*0.30 m^2
- Receiver area = area of the heat pipe exposed to sunlight = 94.2 cm^2
- concentration ratio = 7.32

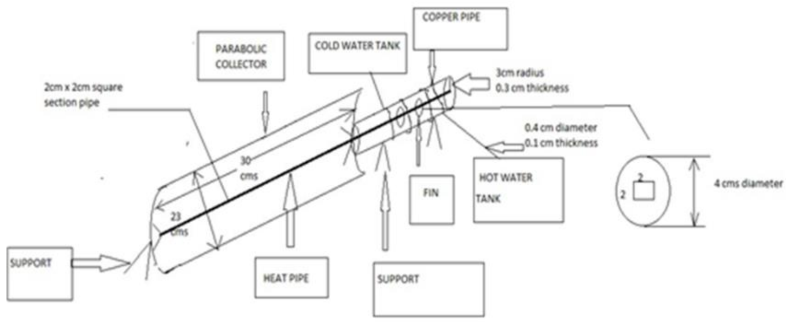


Figure.1. System layout

Heat Pipes:

- Container material – copper
- Working fluid – acetone
- Mesh type – wired metallic screen
- Mesh material – stainless steel
- Length of evaporator section = 0.30m.
- Length of condenser section = 0.20m.
- No adiabatic section
- Diameter of 3 heat pipes = 0.01m.

Container for PCM:

- Material of container over the condenser section is stainless steel
- Diameter of the container = 0.06m.
- Condenser part is completely filled with paraffin wax and contains 2 fins of diameter 0.04m each.
- Diameter of copper tube = 0.02m

Fabrication: The setup has two major components which have been fabricated namely the heat pipes and container of the condenser section. The material chosen for heat pipe is copper tubes due to its excellent thermal conductivity.

A cluster heat pipes are integrated with the help of metal discs, which also acts as fins in the condenser section. These three heat pipes were placed around a copper tube of larger diameter. To increase the absorptivity of the heat pipe it is painted black and placed inside a borosilicate glass container. The container is filled paraffin wax which has been chosen because of its melting temperature range. A copper coil was wound over the container to pass water through it after sunset.

Figure.2. Final setup

Plan of Experiment: During day time solar energy will be concentrated by PTC, transferred by heat pipes and will be stored inside the PCM. The temperature distribution along heat pipe surface, temperature of PCM at various radial distance from heat pipe condenser surface at various time of the day are to be measured. The average temperature of heat pipe surface will give an indication about the performance of PTC. The temperature distribution along heat pipe surface is important in determining performance of heat pipe. The temperature readings in the PCM gives idea about time at which the phase change begins as well as the energy stored in PCM. After sunset, in the evening, water can be circulated through the copper tubes attached over the periphery of PCM stored container to recover the energy. Various readings like Temperature rise of water at different mass flow rate, decrease in temperature of PCM, will give clear picture about discharging process.

3. RESULTS AND ANALYSIS

Average temperature at heat pipe surface: The variation of average temperature at heat pipe surface with time is given in figure 3. As only a small size PTC is used for experiment, the maximum temperature reached is only 82°C which is low compared to other PTC systems. All the thermocouples in the evaporator side were showing almost same reading which indicates the PTC is concentrating energy to heat pipe.

Temperature distribution along heat pipe surface: In Figure.4, the maximum temperature obtained at various sections of heat pipe is shown. It is an indication about the performance of heat pipes. As the condenser section of heat pipe is reaching up to a temperature of 76°C, the performance of heat pipes are satisfactory.

Temperature of PCM: The PCM was getting heated up with time. The temperature was measured at various points in the PCM. There was no much variation which means that the heat transfer rate was good as fins were provided. PCM started melting at around 12.30. The maximum temperature obtained in the PCM was 56°C. Figure.5, shows the variation.

Discharge process: After the sunset the system is tested for discharging the stored energy. For that, water is made to flow through the copper tubes surrounding the PCM container. For each flow rate the rise in temperature is noted down and plotted in figure.6. This process continued until the PCM reached ambient temperature. Thus the total energy recovered from the PCM is found to be around 69.5kJ.

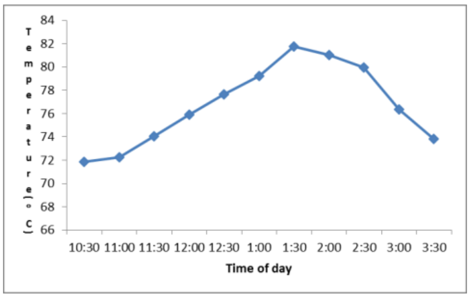
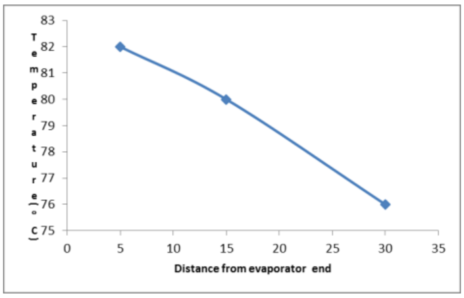


Figure.3. Variation of surface temperature of heat pipe with time



Figur.4. Temperature distribution along heat pipe surface

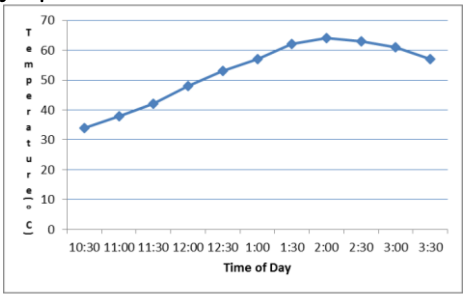


Figure.5. Average temperature of PCM at various times

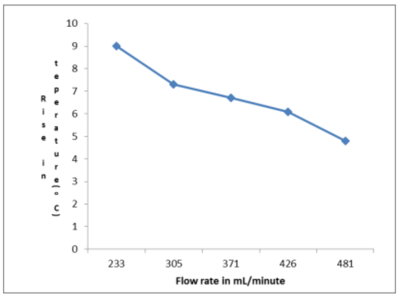


Figure.6. Relation of flow rate with temperature rise

Performance parameters of the system: The instantaneous efficiency of heat pipe and the overall efficiency of the system are found out.

Instantaneous Efficiency of Heat Pipe = (Heat absorbed by the heat pipe) / (Heat incident on the parabolic collector) = 18.89/55= 34.22%

Efficiency of System = (Heat absorbed by PCM) / (Total heat incident on collector) = 69.434KJ/198.72 kJ = 34.94%

4. CONCLUSIONS

A novel thermal energy storage system is devised, fabricated and tested which used a numbers of heat pipes for transferring solar energy to a Phase change material. The temperature obtained was not much high as a small scale system is fabricated. But the efficiency of the system was 35% which was good for a solar thermal system. So the concept can be extended to use in various applications of solar energy like water heating, air heating, refrigeration and power generation, where there is a need for highly efficient storage systems.

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