Design and Development of Heat Pipe Based Flat Plate Solar Collector

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Abstract - **With the current concerns of rise in demand as well as the price of the conventional fuels in the world, there is a need to concentrate more on energy efficiency, conservation and renewable energy. Solar energy is one of the most efficient, clean and affordable energy alternatives. The purpose of this project is to design a flat plate type solar collector integrated with a heat pipe technology. The flat plate solar collector is a means of converting the radiant energy from the sun into thermal energy. Heat pipes are passive devices that have the equivalent of a high thermal conductance. They can be used to remove heat from flat plate collector and transfer the energy to the working fluid inside the heat pipe. For hot water generation, this approach has several advantages over the conventional flat plate collector.**

Index Terms - **Heat pipe, Flat Plate, Solar Collector**

I. INTRODUCTION

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems or for heating swimming pools.

1.1 The Use of Solar Heat

For solar energy applications that involve the heating of hot water and space heating, extremely high temperature is not required. A liquid (usually treated water) or air heated to 42°C to 60°C will suffice. For these low temperature applications the simple, non-concentrating flat-plate collector can be utilized. With this type of solar energy collection there is no need for the more complicated and expensive steering mechanisms that are required when concentrating devices such as lenses or parabolic reflectors are used. Another important advantage is that heat losses which rise with temperature are also minimized. Also the flat plate collector will collect solar energy from the diffused component of the solar intensity. For these reasons, solar energy systems for space and water heating have usually utilized some type of flat plate collector.

1.2Evacuated-tube Collector

One way of improving the performance of a liquid flat-plate collector is to reduce or suppress the heat lost by convection from the top. This is done by having a vacuum above the absorber plate. As a consequence, it become essential to use a glass tube as the cover because only a tubular surface is able to withstand the stresses introduced by the pressure difference.A number of evacuated tube collector (ETC) design have been developed. One design consists of a number of long cylindrical flat-plate collector module side-by-side. Each module is evaluated, cylindrical glass tube containing a rectangular metal absorber plate. The absorber plate has a selective surface coating and heat pipe is attached to it. A glass-to-metal scale is provided between the heat pipe and the end cover of the glass tube. The length of the heat pipe inside the evacuated glass tube constitutes the evaporator section in which heat is absorbed and the fluid inside the heat pipe evaporates. The evaporated fluid rises to the condenser section where it condenses. The heat of condensation is conducted to the fluid flowing in the collector header pipe through an aluminum block clamped on the heat pipe.

The design requires a glass-to-metal seal integrity is difficult to maintain. The need for such a seal is eliminated by developing designs using all-glass- double-walled evacuated tubes. Here each module consists of a long Dewar type evacuated tube with the outer surface of the inner wall being the absorber surface. This surface is selectively coated. The absorbed heat is conducted inwards through the inner glass tube wall and is removed by a number of ways. Collectors differ mainly in the way the heat is extracted from the inside. A heat pipe inside the evacuated tube transports the heat. Aluminum spacers are used to provide the thermal contact between the inner glass wall and the heat pipe shows another design in which a U-tube fixed to a flat metal is inserted in the evacuated tube. The metal fin makes good thermal contact with the inner glass wall and helps the transfer of heat to the liquid flowing through the U-tube.

II. Literature Review

Rittiditch et al. [1] is experimented with flat plate solar collector using a closed and oscillating heat pipe. The system efficiency was 62% at the peak sunlight hours and the operation was corrosion free.

Kabelet al. [2] experimented with flat plate solar collector using heat pipes with inner rings. The collector efficiency reached 63.2% while the maximum recorded fluid outlet was 70.3^{0}C.

Waiet al. [3] using a large integrated heat pipe heated 200 liters of water with maximum efficiency of 66%

Azad [4] experimented with flat plate solar collector using a heat pipe with ethanol as working fluid. The result showed better performance than conventional collector.

Kohli [5] analyzed a heat pipe flat collector theoretically and experimentally. Theoretical efficiency was calculated to be 60.3% while the experimental efficiency was found to be 55.6% only.

III. Experimental Set Up

Experimental set up consists of a copper plate with n number of heat pipes fixed directly on the lower side of the. plate. The working fluid inside the heat pipe is water. The condenser section of the heat pipe is connected directly to the primary storage tank. The copper plate is painted black for maximum solar absorption. The plate and the heat pipes are enclosed in aluminum box. The inner sides and the bottom of the box are insulated by glass wool to minimize side and bottom heat losses. Tempered glass is fixed rigidly as the uppermost layer of the enclosure to ensure maximum transmittance. To prevent heat losses through the primary storage tank, its outer surface is also insulated. The setup is expected to raise the temperature of the water to 70°C.

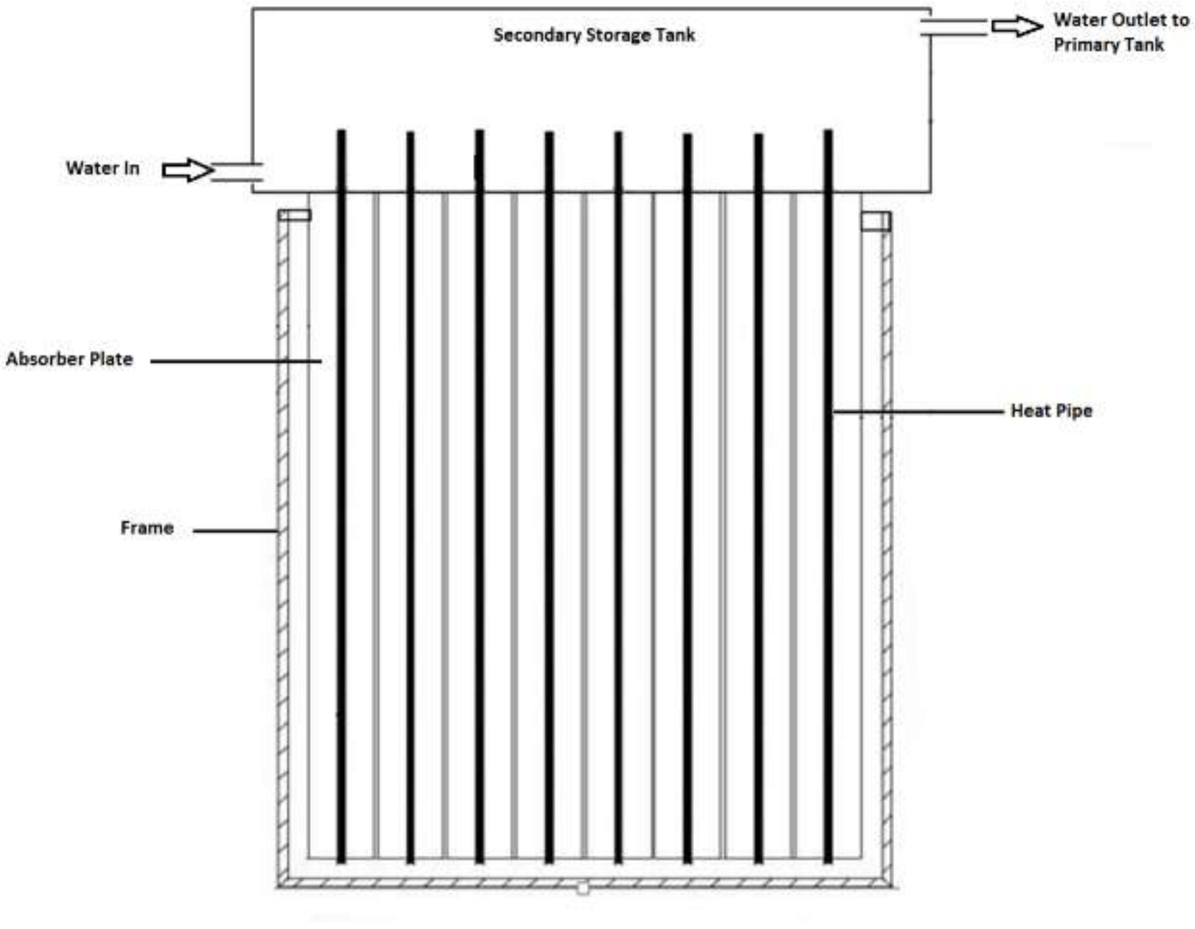

Fig. 1 Schematic Diagram of Set-up

IV. METHODOLOGY

The sunlight passes through the tempered glass and strikes the absorber plate, which heats up changing solar energy into useful heat energy. By means of convective heat transfer, this energy is transferred to the working fluid inside the heat pipes that are directly attached to the plate. Due to gravity, the fluid rests at the bottom of the pipe (the heat source region, or evaporator of the HP), where it will be heated and boiled under the action of the heat crossing the pipe walls through conduction. The vaporized fluid will eventually condense at the upper part of the pipe wall releasing its heat to the heat sink. Once condensed, the liquid droplets will fall back to the bottom of the pipe, completing the cycle and being ready to vaporize and condense over and over again.

V. DESIGN

5.1Design of Absorber Plate

The energy balance on a flat plate solar collector under steady state conditions

$$I_T A_c (\tau\alpha)_e - \dot{Q}_l = \dot{Q}_u \qquad (1.1)$$

Where,

I_T = Total solar radiation incident on the collector per unit area and time

= 800 W/m^2

A_c = Area of the absorber

$(\tau\alpha)_e$= Effective transmittance - absorptance product

$\dot{Q}_u$ = Rate of useful heat collected from the collector

$\dot{Q}_l$ = Rate of heat loss from the collector

$(\tau\alpha)_e = \frac{\tau\alpha}{1-(1-\alpha)\rho_d}$

Where,

τ= transmittance of the cover plate

α =absorptance of the black absorber surface

ρ_d= diffuse reflectance of the cover at $60°$ angle of incidence

Taking standard values of τ, α &ρ_d for calculation

$(\tau\alpha)_e = \frac{(0.9)(0.8)}{1-(1-0.8)(0.15)}$

=0.742

- Now, put value of $(\tau\alpha)_e$ in (1.1);

$$I_T A_c (\tau\alpha)_e - \dot{Q}_l = \dot{Q}_u$$

$$\therefore (I_T)(A_c)(0.742) - \dot{Q}_l = \dot{Q}_u$$

- Assuming heat lost = 15% of solar collector radiation
- Thus the value of can be calculated in terms of A_c
- Now, heat required $\dot{Q}_u$ =to raise the temperature of water from ambient temperatureand desired temperature is given by,

$$\dot{Q}_{req} = \dot{m} C_w \Delta T \qquad (1.2)$$

Where,

$\dot{m}$= mass flow rate of water in kg/s

C_w= specific heat of water

ΔT= temperature difference between ambient temperature and desired temperature

- Efficiency of heat pipe,

(Generally, Heat pipe efficiency is between 0.5 to 0.65)

$$\eta_{HP} = \frac{\text{heat transfer to water}}{\text{heat absorbed}}$$

$$0.6 = \frac{\dot{Q}_w}{\dot{Q}_u}$$

- Hence the value of $\dot{Q}_u$ can be calculated in terms of A_c.
- Now equating the values of $\dot{Q}_u$ and $\dot{Q}_w$ the value of A_c can be calculated.
- Assuming a suitable value for the length of the absorber plate. The breadth of the plate can be calculated by A_c ,

$$b = A_c/l$$

A. Heat Pipe Design

- Heat transfer through heat pipe is given by,

$$Q_{hp} = \rho_v h_{fg} A_v \sqrt{\frac{\gamma R_V T_V}{2(\gamma+1)}} \qquad (2.1)$$

Where,

Q_{hp} = Heat pipe heat transfer rate

h_{fg} = Latent heat

ρ_v= Vapor density

A_v = Area of cross section of heat pipe

$\gamma = \frac{C_p}{C_v}$

R_V = Gas Constant

T_V = temperature of absorber plate

Knowing the values of above-mentioned quantities, the inner curved surface area of the heat pipe can be calculated.

$$A_v = \frac{\pi}{4} {D_i}^2 \qquad (2.2)$$

Here, D_i = inner diameter of heat pipe ID
D_o = outer diameter of heat pipe OD

Now from databook, for commercial heat pipes,

OD/ID = 1.176

So, by putting values of the equation (1) in (2) OD can be calculated.

Effective length of heat pipe can be calculated by,

$$K_{eff} = \frac{Q_{hp} L_{eff}}{A_v \Delta T} \qquad (2.3)$$

Here,

K_{eff} = Thermal conductivity of heat pipe

L_{eff} = Effective length of heat pipe

For L_{eff} ,

$$L_{eff} = \left(\frac{L_{condenser} + L_{evaporator}}{2}\right) + L_{adiabatic} \qquad (2.4)$$

Here,

$L_{condenser}$ = length of condenser section of heat pipe

$L_{evaporator}$ = length of evaporator section of heat pipe

$L_{adiabatic}$ = length of evaporator section of heat pipe

VI. CONCLUSION

The present paper discussed the design and brief review of the recent advances and developments related with the application of the HP solar collector. Some important conclusions are summarized below: -

1) The heat pipe is a closed system so corrosion problems can be eliminated by careful selection of materials.
2) Heat pipes are passive devices so no pumps or fans are required to move the working fluid through the collector.
3) The failure of an individual pipe would not cause the entire system to fail.
4) Use of heat pipe will ensure maximum heat transfer rates to increase the performance of the collector,
5) Proper selection of materials will also ensure protection from freezing
6) Use of nano-fluid in HPFC improves the overall performance of the solar water heater in term of rise in efficiency by 10 to 15 %.

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