

Performance of an evacuated tube collector with heat pipe technology

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Abstract- Renewable energy is mostly used by many countries now days for energy generation and save our environment as well as save conventional fuel resources. Solar energy is one of the most efficient, clean and affordable energy alternatives available today. With the current concerns about global warming and ever increasing energy rates, countries are seriously looking for domestic and industrial usage of solar energy. Cooling, refrigeration, and air conditioning processes are considered essential needs and major requirements for all human beings in our world today. In the present study, a detail review of the application of solar energy by using evacuated tube collector with heat pipe technology for hot water generation has been carried out. The utilization of solar energy for hot water generation system by Evacuated Tube Collector would help in improvement of energy economics, energy consumption and energy efficiency. The review focuses especially on Evacuated Tube Collector with Heat Pipe Technology. The study also includes thermodynamic equation to find out efficiency of Evacuated Tube Collector with Heat Pipe. Also reviewed Design parameters and theoretical model with equations and also reviewed comparison of theoretical and experimental result of Evacuated Tube Collector with Heat Pipe Technology. This technology used mainly for hot water generation which is further used for different purpose compared to any other collector or technology because of higher efficiency, less heat loss, less friction and many more advantages.

Keywords: Renewable energy, Solar energy, Evacuated Tube Collector, Heat Pipe Technology

1. INTRODUCTION

There are still fossil fuels are used by most of the countries for energy generation in different sectors such as domestic, transportation, industrial, commercial, institutional, etc. The sources of fossil fuels are limited. Fossil fuels are conventional energy sources which are limited and may be finished in near future. We pollute our environment by burning fossil fuels. By burning fossil fuels smoke produced which spread in environment and pollute it. Due to fossil fuel there are green house effect and global warming such a serious problem occur in our environment and it effect adversely. Fossil fuel depletes the ozone layer due to this the ultraviolet radiation coming from the sun directly radiated on earth which is harmful for human beings.

Energy is the heart of any country and it has continuous driving power for economic growth. We know that every day the demand for energy is increased. But we also know that the stock of fossil fuel is limited. So, we can't reach demand. We have to find another way to fulfil this demand. We have to find such type of energy source which produce energy as much as conventional fuel like fossil fuel and that source must be not limited. There is one solution of the problem is renewable energy. Renewable energy is Non Conventional energy sources and we can use it again and again and also we can extract high energy from renewable energy sources.

Nomenclature

A_c	collector area (m^2)
C_p	specific heat capacity of solar fluid ($Jkg^{-1}K^{-1}$)
G_t	total global solar radiation on the collector's surface ($W m^{-2}$)
\dot{m}	Solar fluid mass flow rate ($kg s^{-1}$)
Q_{aux}	auxiliary heating requirement (MJ)
Q_{uc}	useful heat collected (J)

Q_{ud}	useful heat delivered (J)
Q_{loss}	supply pipe heat loss (J)
Q_s	Solar yield (MJ)
SF	solar fraction (%)
η_c	collector efficiency (%)
η_s	system efficiency (%)

1.1 Renewable Energy

Renewable energy is defined as energy that comes from resources which are naturally build up again on a human time scale, such as sun light, wind energy, geothermal heat, rain, tidal energy, wave heat etc.

Renewable energy is used in four distinct areas such as air and water heating/cooling, electricity generation, energy services in rural areas and fuels in automobiles. There are significantly increasing energy security, less harmful climatic condition and make benefit economically to countries due to rapid utilization of renewable energy. Two countries named Iceland and Norway already generate all their electricity by renewable energy. Also, some other countries set their goal to produce much more energy using renewable energy in near future. For example in Denmark the government decided to switch the total energy supply to 100% renewable energy by 2050.

Comparison between fossil fuel energy and renewable energy is as given below:

Fossil fuel energy		Renewable energy	
1.	Energy is generated by burning fossil fuel and used where energy is prime factor.	1.	Energy is generated by utilizing energy from renewable sources such as sun, wind energy, tidal energy, geothermal energy, etc and converts it into useful form by different technologies.
2.	Energy from fossil fuel can pollute our environment.	2.	Energy from renewable sources is naturally and never pollute environment.
3.	It adversely affect environment and produce some serious problem such as green house effect and global warming.	3.	Renewable energy never produces any adverse effect on environment.
4.	W can get much more energy from fossil fuels than renewable energy.	4.	We can't get more energy than fossil fuels because of developing different technologies to convert renewable energy in useful form.
5.	Still most of the energy required is fulfilled by fossil fuel.	5.	Still we can't replace conventional energy sources by renewable energy sources.
6.	The sources of conventional energy such as fossil fuels are limited and it might be finished in near future.	6.	The sources of renewable energy are very wide and huge and also it will never finish because we can utilize it again and again.

There is one suitable solution of all environmental problems like- accumulation of greenhouse gases, global warming issue, etc. And the solution is Renewable energy. The energy from renewable sources is pollution free and environment friendly but we can't utilize it by 100%. So, different technologies are developed to use more renewable energy for energy production [9].

To save conventional energy sources and to protect the environment, renewable energy is the best aspect. A continuous and significant development of different technologies for utilizing renewable energy sources is remarkable for the future of a balanced global energy economy. As the demand for energy is increased, use of fossil fuel is also increased but only renewable energy sources can fill that gap between energy demand and use of fossil fuel. Because by using renewable energy sources we can reach demand by using less conventional energy like fossil fuels. Need of healthy and hygienic food products, air-conditioning, hot water supply, stored horticulture product for long time are such factors which encourages the use of renewable energy in industrial production and domestic process [13].

1.2. Solar Energy

All Solar energy is nothing but only heat from sun and radiant light. The solar energy is used in different technologies such as solar heating, solar cooling, solar thermal energy, photovoltaic, solar architecture and artificial photosynthesis. Among all of the renewable energy sources solar energy is an important source of energy. Solar energy technologies are classified as active solar and passive solar energy based on the way they capture and distribute solar energy or convert it into solar power. There are different active solar techniques to use solar energy like- photovoltaic system, solar water heating/cooling and concentrated solar power. Different passive solar energy techniques include orienting a building to the sun, selecting materials with favorable thermal mass or light dispersing properties and designing spaces that naturally circulated air. Solar energy is used everywhere now a days in different purposes. Somewhere it is used for electricity production, hot water generation, air-conditioning, refrigeration, domestic purpose and cooking etc.

In 2011, the International Energy Agency said that “the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries’ energy security through reliance on an indigenous, inexhaustible and mostly-import – independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared”.

There are different types of renewable energy are available such as – solar energy, wind energy, geothermal energy, tidal energy, etc. Solar energy is mostly used from all of the above mentioned energies because of its more likely distribution in nature and abundant source available. Solar energy is environment friendly, clean, low cost and easily available form of renewable energy. There are thermonuclear reactions are occur inside the core of the sun, which resulting electromagnetic radiation released by sun is known as solar energy. A huge amount of solar radiation is received by earth’s surface. As increasing energy prices, limited conventional fuels and increase global warming guide many countries to use renewable energy such as solar energy, wind energy, etc instead of conventional fuels. Solar energy is utilized for different purpose by different technologies such as photovoltaic, solar collectors, etc. Solar energy is used for different purpose like- electricity production, air conditioning, power plant, hot/cold water generation, refrigeration technologies, industrial process, domestic purpose, etc now a day. There are different types of collectors to collect solar radiation and convert it into useful form. Still we can’t use 100% of solar energy because of different losses. So, there are still many researches going on these areas to use more available solar energy and also for increasing performance of solar collector, resulting increase its efficiency.

2. SOLAR COLLECTORS

A Solar thermal collector collects radiation coming from sun (solar radiation) and converts that collected radiation (heat) into useful form. An absorber is placed inside the solar thermal collector to collect heat from sun radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) the ultraviolet (short) wavelengths. Average solar energy which coming on earth’s surface is 1000 watts per square meter under clear skies, depending upon weather conditions, locations and orientation.

There are different solar collectors for different purposes. Some collector collect radiation to produce electricity, some collectors collects radiation for hot/cold water generation, air collectors used for air conditioning, etc. Simple collectors are typically used in residential and commercial buildings for space heating.

There are two forms of solar collectors (1) Concentrating collectors and (2) Non-concentrating collectors. In Non-concentrating collectors, the collector area is the same as the absorber area and whole solar panel absorbs light. In concentrating collectors, the collector area is bigger than the absorber area.

There are two types of solar collectors: (1) Flat plate and (2) Evacuated tube collectors.

Both of the above collectors are used for domestic hot water or cooling with absorption chillers and space heating.

2.1 Flat plate collectors

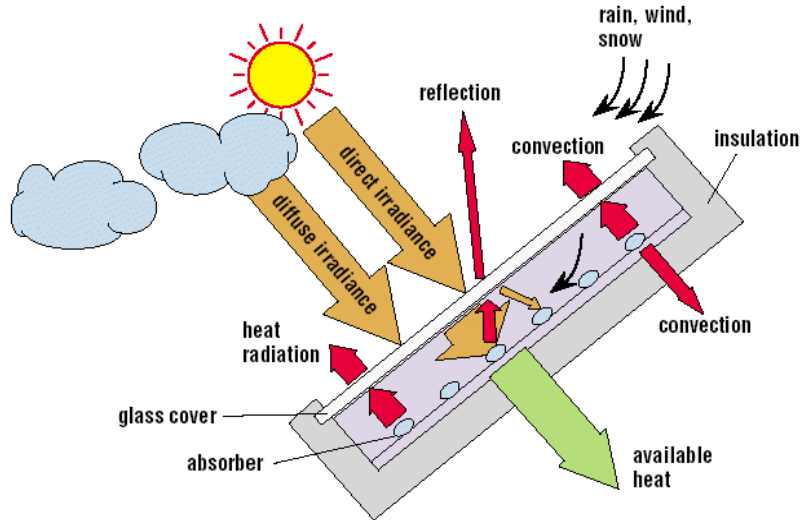


Figure1. Schematic of a flat plate collector

Flat plate collectors consist of

- (1) A dark flat-plate absorber,
- (2) A transparent cover,
- (3) A heat-transfer fluid and
- (4) A heat insulating backing.

A dark flat-plate absorber has a thin absorber sheet which is backed by a coil of fluid tubing. A grid or coil of fluid tubing is placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid is passed through tubing to transfer heat from the absorber to an insulated water tank.

In flat plate collectors first sun radiation is absorbed by absorber plate and converts solar energy into heat energy. This heat energy then transferred to the liquid (water) which is circulating through pipes which attached to the absorber plate. Absorber plates are painted with "selective Coatings" which absorb and retain heat better than ordinary black paint. The absorber plates are made from copper or aluminium because this type of metal is good conductor of heat which transfers more amount of heat by calculation. Mainly copper is used for absorber plate and it is more expensive, but less corrosive than aluminium.

2.2 Evacuated Tube Collectors (ETC)

Evacuated tube collectors are made from number of evacuated glass tubes. Each evacuated glass tube has an absorber plate in which heat pipe is placed inside the tube. Solar radiation incident on evacuated glass tube is absorbed by absorber plate and convert this solar radiation into heat. This heat is transferred from absorber plate to the heat pipe. This heat is utilised to generate hot water by transferring heat from heat pipe to domestic water which is passing through heat exchanger called "manifold". So the heat is transferred generally from absorber tube to insulated hot water tank. The manifold is wrapped in insulation and covered by a protective sheet metal or plastic case. There are vacuum is created inside the glass tube so that it greatly reduced convection and conduction heat loss generally occurred outside of the tube. Therefore, we can get higher efficiency in evacuated tube collectors than flat plate collectors, especially in colder conditions. In warmer condition or in warmer climates this advantage is largely lost, except in those cases where very hot water is desirable.

Evacuated Tube Operation

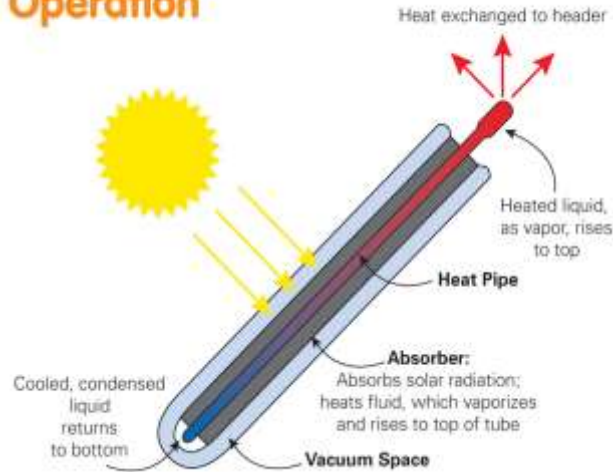


Figure2. Evacuated tube collector with heat pipe

There are different types of evacuated tube collectors available such as

- (1) Glass- metal evacuated tube collectors
- (2) Glass- Glass evacuated tube collectors

Glass –metal evacuated tube collectors further classified as concentric fluid inlet and outlet and separated inlet and outlet pipes according to flow of fluid in pipes.

There is a single glass tube in concentric fluid inlet and outlet tube. There is a copper heat pipe or water flow pipe with attached fin is inside the tube. In this type of construction each single pipe and absorber fins are free to rotate in any direction (angle) even if the collector is mounted horizontally.

Glass- metal with separated inlet and outlet pipes evacuated tube collectors are of traditional type collector. The shape of absorber in this type of collector is flat or curved. Vacuum is desirable inside the tubes and at lower working temperature efficiency of this type of evacuated tube collector is high.

In construction of glass-glass evacuated tube collectors two glass tubes fused together at one end. There are coating of integrated cylindrical metal absorber is available in the inner tube. This type of evacuated tube collectors is less efficient than the glass-metal type but cheaper in cost and more reliable than glass-metal type. Glass- Glass collectors are more efficient at high working temperatures.

Comparison of flat plate collector (FPC) and Evacuated tube collector (ETC) is as given below.

Flat plate collector (FPC)		Evacuated Tube Collector (ETC)	
1.	In flat plate collector an absorber plate with a sheet of copper, painted or coated black is bonded to pipes of transfer fluid.	1.	I evacuated tube collector a glass tube with vacuum inside it is surrounding an absorber plate or area.
2.	FPC has low cost.	2.	ETC has higher cost.
3.	Flat plate collector is more efficient than evacuated tube collector at ambient temperature.	3.	ETC is more efficient than FPC at lower working temperatures (conditions).
4.	The design of FPC is easy.	4.	The design of ETC is difficult because of vacuum

			inside the tube.
5.	FPCs are sensitive to sun angle and orientation.	5.	ETCs are less sensitive to sun angle and orientation.
6.	FPCs have longer life.	6.	ETCs have less life than FPCs.
7.	Flat plate gives better year round performance.		Performance of ETCs is less than FPCs.

2.3 Heat Pipe Technology

A heat pipe is a heat transfer device which transfers heat between two solid surfaces by using two principles as thermal conductivity and phase transition.

There are two sections are available mainly such as evaporation section (hot interface) and condensation section (cold interface). A liquid inside the heat pipe evaporates at hot interface by absorbing heat from the absorber. That generated vapour then travels to the cold interface and release latent heat to the working fluid passing from the manifold. So the liquid inside the heat pipe is condenses back into a liquid which again travels to evaporation section by capillary action, centrifugal force or gravity. Hence the cycle is completed and it continuously repeats to transfer high amount of heat. Heat pipes are highly effective conductors because of the very high heat transfer coefficients for boiling and condensation. Heat pipe length may affect the effective thermal conductivity of it. Thermal conductivity can approach 100 kW/ (m-K) for long heat pipe than approximately 0.4 kW/ (m-K) for copper. The schematic of heat pipe is shown as figure given below.

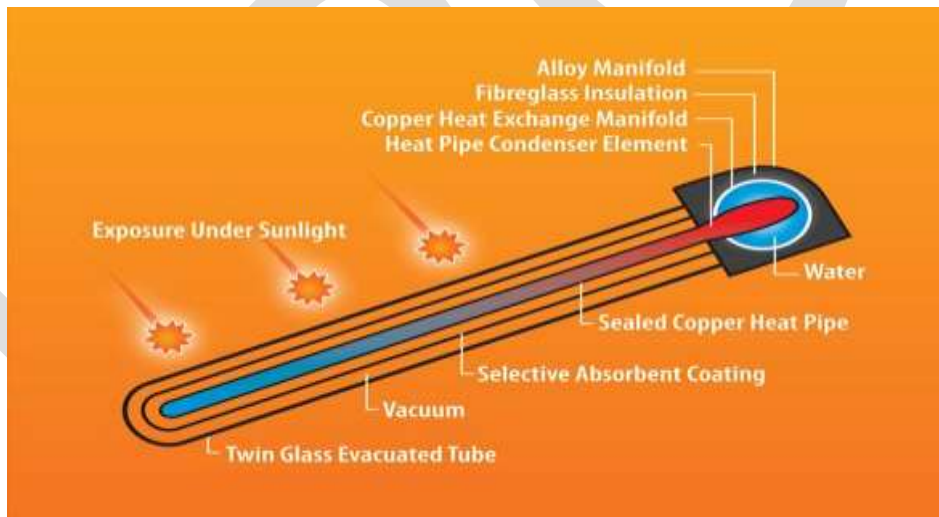


Fig.3. Schematic of heat pipe technology

Structure, design and construction:-

A typical heat pipe is nothing but a sealed pipe or tube which is made with compatible material with working fluid such as for water heat pipe copper is suitable and for ammonia heat pipes aluminium is suitable. When heat pipes are empty at that time for maintaining vacuum inside it a vacuum pump is used. After creating vacuum inside the heat pipes it fills partly with working fluid and then sealed. The working fluid mass is chosen so that the heat pipe contains both vapour and liquid over the operating temperature range. Below the operating temperature, the liquid is too cold and cannot vaporize into a gas. Above the operating temperature, all the liquid has turned to gas, and the environmental temperature is too high for any of the gas to condense. Whether too high or too low, thermal conduction is still possible through the walls of the heat pipe, but at a greatly reduced rate of thermal transfer. Working fluids are chosen according to the temperatures at which the heat pipe must operate. Water heat pipes are sometimes filled by partially filling with water, heating until the water boils and displaces the air, and then sealed while hot.

There must be a saturated liquid and its vapour present inside the heat pipe for transferring heat. The saturated liquid present inside the heat pipe is vaporized and then travels to the condensation section where that vapour condenses by releasing latent heat and that saturated liquid again returns to the evaporation section by action of capillary, centrifugal force or by gravity. In a saturated heat pipe, the condensed liquid is returned to the evaporator using a wick structure exerting a capillary action on the liquid phase of the working fluid. Wick structures used in heat pipes include sintered metal powder, screen, and grooved wicks, which have a series of grooves parallel to the pipe axis. When the condenser is located above the evaporator in a gravitational field, gravity can return the liquid. In this case, the heat pipe is a thermosyphon. Finally, rotating heat pipes use centrifugal forces to return liquid from the condenser to the evaporator.

Heat pipes contain no mechanical moving parts and typically require no maintenance, through non-condensable gases that diffuse through the pipe's walls, resulting from breakdown of the working fluid or as impurities present in the material, may eventually reduce the pipe's effectiveness at transferring heat. The advantage of heat pipes over many other heat-dissipation mechanisms is their great efficiency in transferring heat.

The most commonly used envelope (and wick)/fluid pairs include:

- Copper envelope/Water working fluid for electronics cooling. This is by far the most common type of heat pipe.
- Copper or Steel envelope/Refrigerant R134a working fluid for energy recovery in HVAC systems
- Aluminium envelope/Ammonia working fluid for Spacecraft Thermal Control
- Superalloy envelope/Alkali Metal (Caesium, Potassium, Sodium) working fluid for high Temperature heat pipes, most commonly used for calibrating primary temperature measurement devices.

3. PERFORMANCE EVALUATION

3.1 Performance of heat pipe

Chunjing Wong, Weiye Feng, Qingtai Jiao, Shai Li and Dejun Cai et al [16] carried out study on heat transfer capacity of solar horizontal heat pipe.

They carried out study to determine the optimum range of volumes of the working fluid for the solar horizontal heat pipe and also to determine characteristics of the sensitivity of the heat pipe performance to the installation angle. So a researcher can design the horizontal heat pipe collectors optimally.

The heat transfer performance of solar horizontal heat pipe is mainly influenced by filling amount and it is one of the key parameters of the solar horizontal heat pipe. They obtain optimum heat transfer performance of the solar horizontal pipe when the level height of working fluid is about 19% - 22% of the inner diameter of the solar horizontal pipe. The solar heat pipe is also sensitive to angle. The heat transfer capacity decreased significantly at a small negative angle and the heat transfer capacity increased significantly at a small positive angle.

3.2 Performance of Flat plate collectors with heat pipe

M. Hammad et al [1] investigated experimental study of the performance of a solar collector cooled by heat pipes. He described the performance of a flat plate solar collector cooled by a set of heat pipes, designed and manufactured locally to work at low temperature conditions equal to that of flat plate solar collectors. He calculated the efficiencies and quantities of energy transferred to a water storage tank and resulted that it was comparable to those obtained by using water cooled solar collector. The collector efficiency mainly depends on time of day, solar intensity; ambient temperature and flat plate mean temperature. The unit was less expensive and suitable for rural areas because it was natural circulation water cooled unit. Following figure shows the effect of solar intensity and ambient temperature combine to affect the efficiency daily distribution.

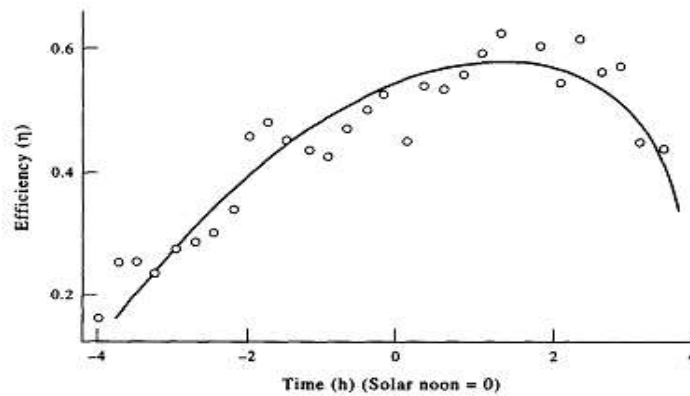


Fig.4. Efficiency vs. Time

Some important merits of unit are free of icing, free of corrosion and cooling of the daily heated water at night. He measured efficiency of unit was 60% and also noticed that the unit was working at low temperature conditions and give satisfactory performance.

E. Azad et al [5] studied the theoretical and experimental investigation of heat pipe solar collector. He investigated the thermal behaviour of a gravity assisted heat pipe solar collector theoretically and experimentally. The developed theoretical model was based on effectiveness-NTU method, for evaluating thermal efficiency of the collector, the inlet, outlet water temperatures and heat pipe temperature. He also determined optimum value of evaporator length to condenser length ratio. There is a very high thermal conductance structure in the heat pipe. This structure allows the heat transportation with a temperature drop of smaller magnitude. Heat pipes consist of a sealed container with a small amount of working fluid. There are two sections in heat pipe as: evaporator section and condenser section. In evaporator section the heat is transferred as latent heat energy by evaporating the working fluid in a heating zone. In condenser section the vapour is returned to the heating zone by the capillary structure which lines the inner wall of the container and the cycle is completed.

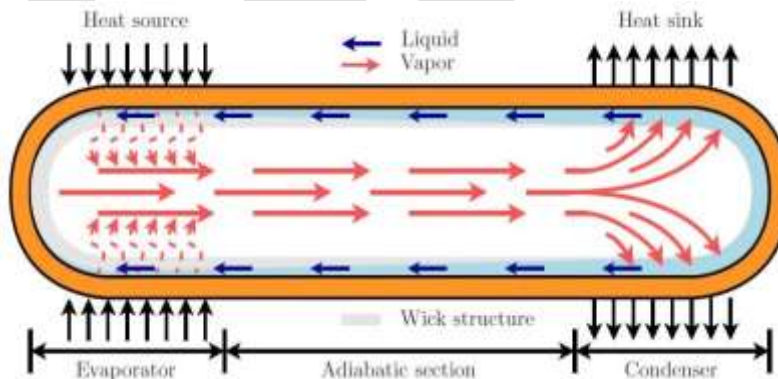


Fig.5. Heat Pipe Schematic

Gravity assisted heat pipes are unidirectional conductors-they behave as thermal diode. Heat is transferred from evaporator section to condenser section only but not in reversed direction, if we oriented heat pipe properly. So we can reduce heat loss when absorber is at lower temperature than the liquid flow inside the heat exchanger. Advantages of heat pipes are less corrosive, redundancy and if one heat pipe may fail then that does not effect on the performance of the collector. Only heat exchanger section must be insulated so that we can avoid freezing problem.

The condenser of the heat pipe is elevated so that the condensate returns to the evaporator with the assistance of gravity and we can get high heat transfer capability. There are no wick is required in the condenser section while for circumferential distribution a wick structure is required. When the heat pipe is operating in gravity assisted mode, a high heat transfer capability can be achieved. Further, no wick is required in the condenser since gravity drains the condensate from the wall to the paddle. However, a wick structure is required for circumferential distribution of liquid in the evaporator.

He experimentally investigated the thermal performance of heat pipe solar collector together with a simple theoretical analysis. Theoretical model can suggest an optimum heated length-cooled length ratio, so collector absorbs more heat and increase the overall amount of useful heat. With the increase of the heated length-cooled length, L_e/L_c , the absorber area will increase which may result in increased solar energy by absorber plate and also the heat loss from the absorber. Also, heat transfer coefficient in condenser will increase and hence increase the heat transfer rate in the condenser.

E.Azad et al [10] studied an assessment of three types of heat pipe solar collectors. He installed all of three collectors in parallel to each other. When all of three collectors are operating under variable conditions such as wide range of incidence solar radiation, the characteristics of three collectors are noticed by him.

All of three collectors of testing unit are as given below:

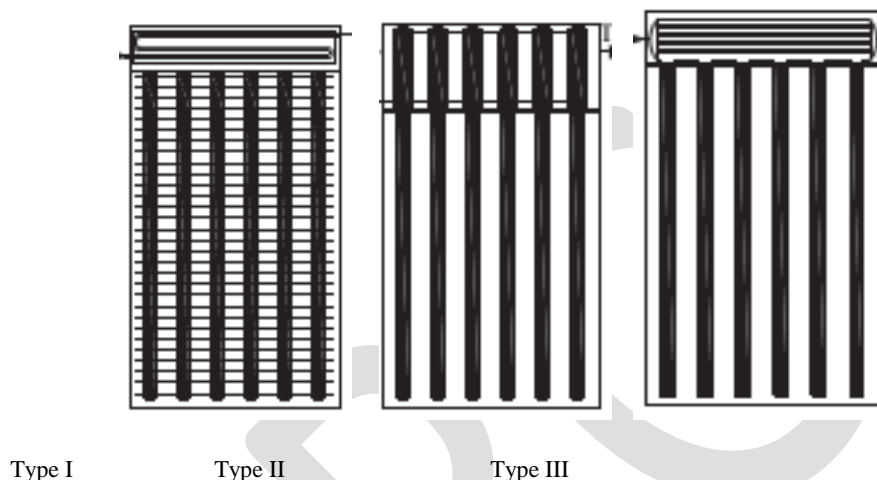


Fig.6. Heat pipe solar collector

Efficiency of three collectors is as given below:

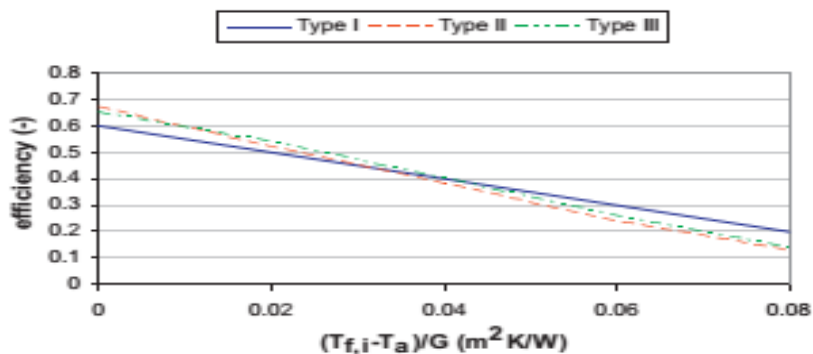


Fig.7. Heat pipe solar collector's efficiency line

He noticed that Type- I collector as shown above figure that are with fins gave better efficiency among three collectors. The fins attached with tubes can increase the performance of collector. This type of collector is of low cost and easily produced but leakages are there.

3.3 Performance of Evacuated Tube Collectors (ETC) with heat pipe

Evacuated tube collectors are such collectors which collect solar radiation (energy) and convert it into heat energy. With the help of heat pipe technology evacuated tube collector can transfer solar energy into heat energy. In heat pipe mainly two sections are available named evaporative section and condensation section. In evaporative section fluid inside the tube is evaporated and then vapours travel to condensation section where that fluid condensed and working fluid or air is heated by taking heat from the vapour inside the heat pipe at heat exchanger inside the manifold.

Convective heat loss is less in evacuated tube collectors because absorber surface is placed inside the vacuum. We can also reduce radiation loss by using a low emissivity absorber surface. A heat extraction from long thin absorber is the main problem with evacuated tube solar collector. Following methods are used to extract heat from evacuated tubes:

- Heat pipe
- Flow through absorber
- All glass tubes
- Storage absorber.

G.L. Morrison, I. Budihardjo, M. Behnia et al [2] studied water-in-glass evacuated tube solar water heaters and found that evacuated tube solar collectors have better performance than flat plate solar collectors, for high temperature operations.

S.B.Riffat, X.Zhao and P.S.Doherty et al [3] developed a theoretical model to investigate thermal performance of a thin membrane heat-pipe solar collector. He designed and constructed a thin membrane heat-pipe solar collector so that it can collect solar radiation efficiently with low cost. He also developed a heat balance equations for analysis purpose. He analysing heat transfer processes occurring at top cover, absorber and manifold areas. The test efficiency was found to be in the range 40-70%, which is a bitter lower than the values predicted by modelling.

A comparison of testing and modelling results of the thin membrane heat pipe solar collector is shown as following graph.

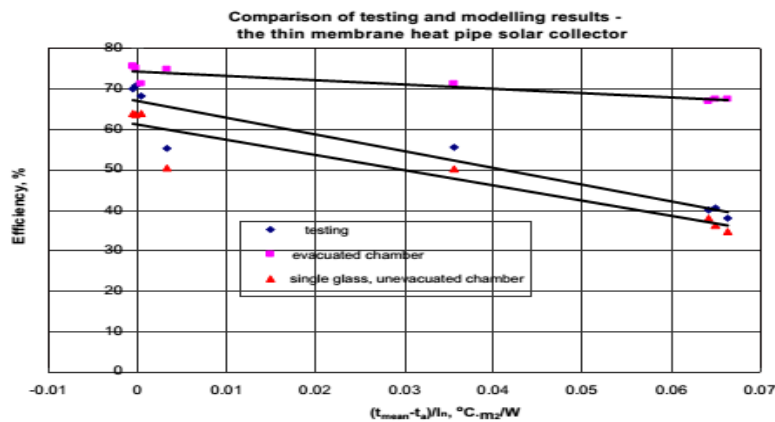


Fig.8. Comparison of testing and modelling result

'Miniature' heat pipes cost are less than normal heat pipes used in evacuated tube collector or flat plate heat pipe solar collector. The measured efficiency of the test was in the range of 40-70%. This value is lower than the prediction for evacuated case by modelling while higher than the prediction for unevacuated chamber with single glass cover. This was happened because in case of evacuated one the heat transfer resistance is more due to inert gas, argon is used for filling the chamber after evacuated. In unevacuated chamber heat resistance is less due to air inside the chamber. If we comparing both then we can find that the convective or conduction loss is more in unevacuated chamber than evacuated one.

Yong Kim and Taebeom seo et al [4] studied thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tube. The thermal performance of a glass evacuated tube solar collector is investigated numerically and experimentally for two layered glass tube and absorber tube. The working fluid is an air in this solar collector. The performance of four different shapes of absorber tubes of solar collectors are carried out to find out the best and optimum shape of absorber tube. They also compared the performance of collector model and simplified model in which only beam radiation is considered. They observed that the parameters which seriously affected the performance of solar collectors are incidence angle of solar radiation, shape of the absorber and arrangement of collector tube. The centre distance increases, the number of collector tube decreases and hence decrease utilized solar energy. They test the four models with only beam radiation for single collector tube and then beam radiation with the diffuse radiation and shadow effect for different collectors.

The four cross-sections of different shapes of absorber tubes are shown in following figure.

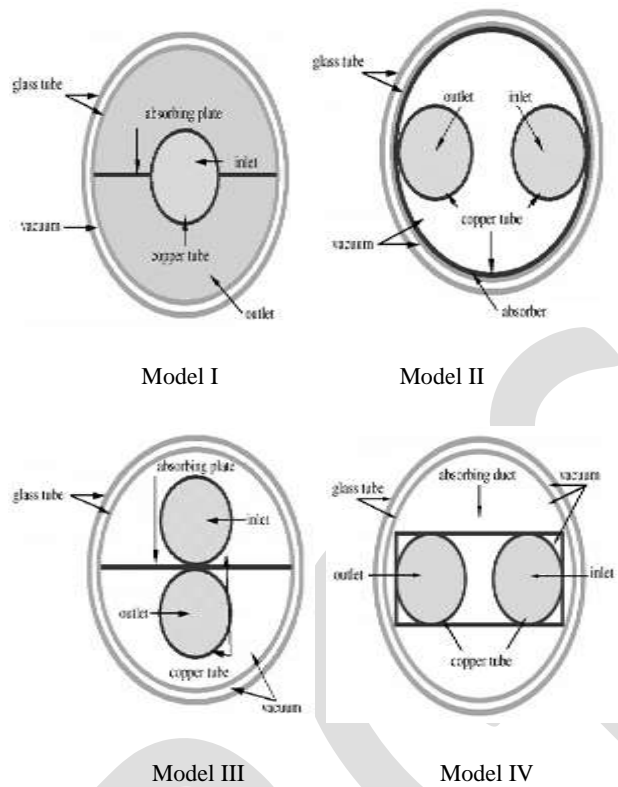


Fig.9. Four cross-sections of different shapes of absorber

Model II gave the best performance among four different collectors, when we considered only beam radiation. Initially, when the incidence angle was small, the efficiency of model III was high but as soon as incidence angle increases the efficiency of model III becomes higher than that of model III. When the effects of the diffuse irradiation and the shadow due to adjacent tubes were considered, the performance of model III was the best for all ranges of the incidence angle.

I. Budhihardjo, G.L.Morrison et al [6] investigated the performance of water –in-glass evacuated tube solar water heaters. The performance was evaluated using experimental measurement of optical and heat loss characteristics and a simulation model of the thermosyphon circulation in single ended tubes. The performance of water-in-glass evacuated tube solar collector system was compared with flat plate solar collector in a range of locations.

The schematic of water-in-glass evacuated tube solar water heater is as given below.

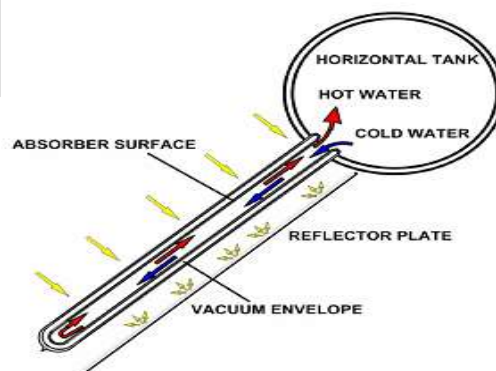


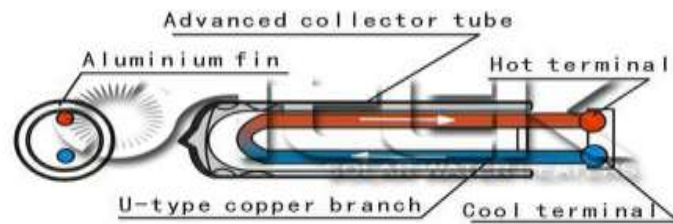
Fig.10. Natural circulation flow in a water-in-glass solar water heater

They prepared a model of water-in-glass evacuated tube solar water heaters and simulate the performance of it. An evacuated tube system with 30 tubes had slightly lower energy savings than a two panel (3.7 m²) flat plate system.

Liangdong Ma, Zhen Lu, Zhang and Ruobing Liang et al [7] studied thermal performance analysis of the glass evacuated tube solar collector with U-tube. They investigated thermal performance of the individual glass evacuated tube solar collector by analytical method. The solar collector is two layered glass evacuated tube and the absorber film is deposited in the outer surface of the absorber tube. Using one dimensional analytical solution, the heat loss coefficient and heat efficiency factor are analyzed. Also, they studied the influence of air layer between the absorber tube and the copper fin on the heat efficiency. The function relation of the heat loss co-efficient of the glass evacuated tube solar collector with temperature difference between the absorbing coating surface and the ambient air is nonlinear.

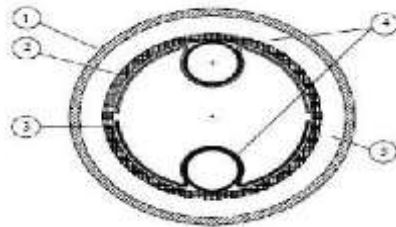
Anti-freezing, rapid start-up, resistance to high pressure, easy installation and maintenance, etc are the advantages of heat pipe evacuated tube solar collectors. Many countries have paid more and more attention to utilise solar energy and increase country economy by saving conventional fuels as much as possible. But the heat pipe evacuated tubular must maintain the vacuum environment. In the practical application, it is very difficult to maintain a vacuum inside the tube because lots of non-condensable gas will be produced in the heat pipe at the running process of the system. The thermal performance of the heat pipe will be subject to serious influence because of the accumulation of non condensable gas.

Currently, U-tube glass evacuated tube solar collector is much more widely used compared with the heat pipe. U-tube glass evacuated tube solar collector is shown in the figure given below.



1- Outer Glass

Tube



2- Absorber tube

3- Copper Fin

4- U- Tube

5- Vacuum Jacket

Fig.11. Glass evacuated tube solar collector with U-tube (a) Illustration of the glass evacuated tube (b) cross-section

The influence of the thermal resistance of air layer on the heat efficiency is large. To evaluate thermal performance of the glass evacuated tube solar collector, heat efficiency as well as surface temperature of the absorbing coating is important parameters. The efficiency increases with increase of solar radiation intensity, but it reaches gradually to a constant. Variation of efficiency and coating temperature with radiation intensity is as shown below.

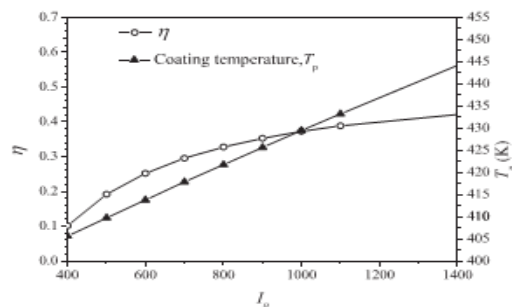


Fig.12. Variation of efficiency and coating temperature with radiation intensity

Dan Nchelatbe Nkwetta, Mervyn Smyth, Aggelos Zacharopoulos and Trevor Hyde et al [9] carried out optical evaluation and analysis of an internal low concentrated evacuated tube heat pipe solar collector for powering solar air conditioning systems. This analysis was carried out to enhance the collection of solar radiation for medium temperature applications. Ray trace analysis was carried out at different transverse angles to determine the quantities such as optical efficiencies, related optical losses and flux distribution on the absorber of the internal low-concentrating evacuated tube heat pipe solar collector. They investigated the truncated internal low-concentrating evacuated tube heat pipe solar collector with the respective acceptance half angle as shown in figure.

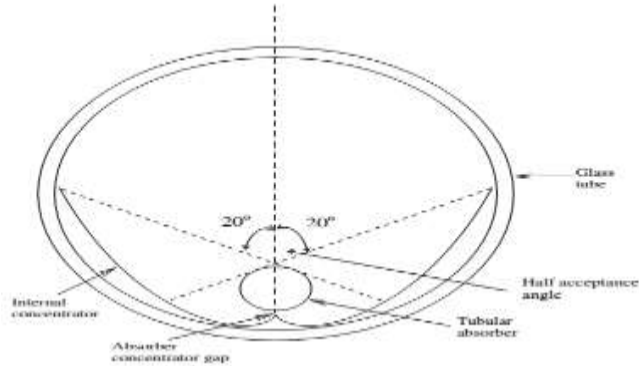


Fig.13. the truncates internal concentrating evacuated tube heat pipe (ICETHP) solar collector configuration

Ray trace diagram for the internal low-concentrated evacuated tube heat pipe solar collector with solar radiation incident at different transverse angles are as given below.

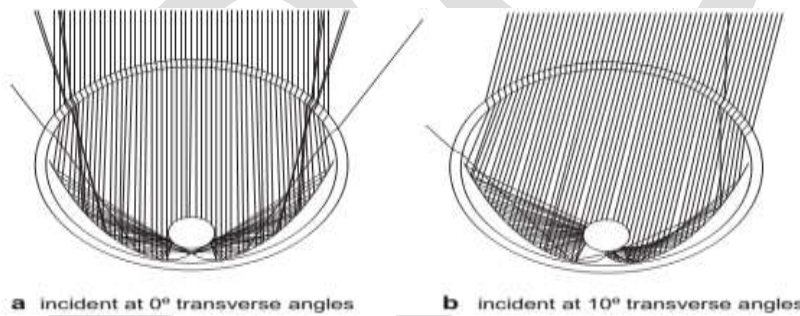


Fig.14 Ray trace diagram for the internal low-concentrated evacuated tube heat pipe solar connector with solar radiation incident at (a) 0° (b) 10°

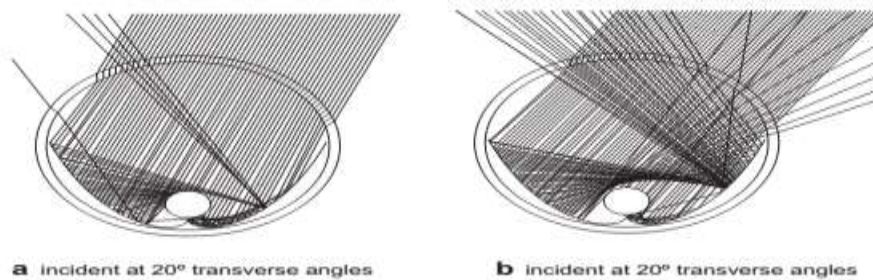


Fig.15 Ray trace diagram for the internal low-concentrated evacuated tube heat pipe solar connector with solar radiation incident at (a) 20° (b) 30°

The variation in optical efficiencies at different transverse angles showed a non-linear relationship. The truncated internal reflector design reduced reflector losses and cost of the reflective material. We increased the irradiance level on the heat pipe absorber and reduce convective heat losses with combine use of concentration and evaluation. They achieved higher temperatures with larger temperature differential and hence improvement in the thermal performances.

Bin Du, Eric Hu and Mohan Kolhe et al [11] carried out an experimental platform for heat pipe solar collector testing. The parameters included in experiment were receiver and absorber areas, the effective heat capacity, the incidence angle modifier and the pressure drop and also its correlations with the instantaneous efficiency were investigated.

The pressure drop was an important parameter for the design of the solar collector. First we have to check that there were no impurities and bubbles in the moving working fluid before measuring the pressure drop. The measured parameters are the temperature of working fluid at the inlet collector t_i , the mass flow rate of working medium, the pressure difference between the inlet and outlet of collector. The calculation formula of the collector's pressure drop is:

$$\Delta p = 51838 m^2 + 1807 m \quad (1)$$

Where, m = mass flow rate of working medium

All the measuring parameter's performance was as desirable and data of experimental and theoretical were within range.

Lacour Ayompe and Aidan Duffy et al [12] studied thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial.

Evacuated tube collectors (ETCs) have glass tubes with vacuum generated inside it. The absorber surface which absorbs solar radiation is located inside the glass tube and absorber surface has different shapes. ETCs may be subdivided in two types: (1) 'direct flow through' (or 'water-in-glass) and (2) 'heat pipe'. Direct flow through evacuated tube collectors have a set of glass tubes which are normally connected with a tank or shell. A larger diameter glass tube is used to surround each tube with the annular space between the tubes evacuated to reduce heat losses. The heat transfer liquid is heated as it circulates in the tubes.

A heat pipe (HP) has tubes which has high thermal conductance and there are small amount of working fluid is present inside the heat pipe. At a heating zone of heat pipe working fluid is evaporating by absorbing a latent heat of evaporation. That evaporated vapour then travel to cooling zone and it condenses by rejecting heat to fluid which flow through manifold. Then the condensate return back to the heating zone and the cycle complete. The condensate returns back to evaporative section by capillary action, gravity or by wick structure. The tubes are mounted with the metal tips projecting into a heat exchanger (manifold) containing flowing water or water/glycol. Heat is transferred into the manifold and through circulation pipe work to be used in heating and/or hot water applications.

A heat pipe evacuated tube collector (HP-ETC) has a heat pipe inside a vacuum generated tube. Due to vacuum present inside the tubes it reduces convection and conduction losses, so the collectors can operate at higher temperatures than flat plate collectors (FPCs). FPCs and HP-ETCs can collect both direct and diffuse radiation. Heat pipe evacuated tube collectors have higher efficiency at low incidence angles. Typically heat absorbing fins are attached to the tubes to maximise thermal gains.

The main difference in thermal performance between a HP-ETC and conventional HP technologies lies in the heat transfer processes from the absorber tube wall to the energy transporting fluid. In the HP-ETC there are three processes involved which are evaporation, condensation and convection. For conventional HP solar collectors, heat transfer occurs only in the absorber plate. Solar collectors with HPs have a faster response time because it has lower thermal masses.

HPs operate like a thermal diode, i.e., with unidirectional heat flow. This minimizes heat loss from the transporting fluid when incident radiation is low. Furthermore, when the maximum design temperature of the collector is reached, additional heat transfer can be prevented. This prevents overheating of the circulation fluid, a common problem in many solar collector systems.

The use of HP-ETCs in solar water heating systems (SWHSs) is increasing worldwide because of their high thermal efficiencies and operating water temperatures when compares to flat plate collectors (FPCs). Heat pipe evacuated tube and manifold is as shown in figure below.

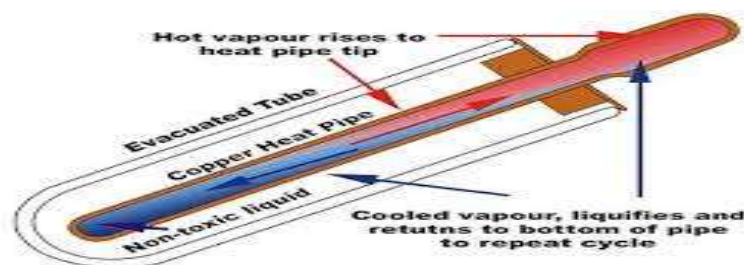


Fig.16 Heat pipe evacuated tube collector

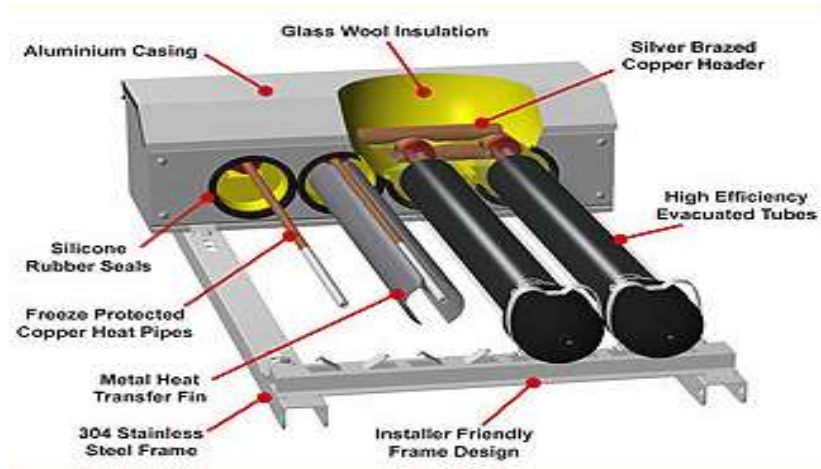


Fig.17. Manifold

Energy Performance Analysis:

1. Energy Collected:

The useful energy collected by the solar energy collector is given as:

$$Q_{uc} = \dot{m} C_p (T_{c,outlet} - T_{c,inlet}) \tag{2}$$

2. Energy delivered and supply pipe losses:

The useful energy delivered by the solar coil to the hot water tank is given as:

$$Q_{ud} = \dot{m} C_p (T_{sc,inlet} - T_{sc,outlet}) \tag{3}$$

Supply pipe losses were due to the temperature drop as the solar fluid flowed between the collector outlet and the solar coil inlet to the hot water tank. These losses were calculated as:

$$Q_{Loss} = \dot{m} C_p (T_{sc,inlet} - T_{c,inlet}) \tag{4}$$

3. Solar Fraction:

The solar fraction (SF) is the ration of solar heat yield to the total energy requirement for water heating and is given as:

$$SF = \frac{Q_s}{Q_s + Q_{aux}} \tag{5}$$

4. Collector efficiency:

The collector efficiency is calculated as:

$$\eta_c = \frac{\dot{m} C_p (T_{c,outlet} - T_{c,inlet})}{A_c G_t} \quad (6)$$

5. System Efficiency:

The system efficiency is calculated as:

$$\eta_s = \frac{\dot{m} C_p (T_{sc,inlet} - T_{sc,outlet})}{A_c G_t} \quad (7)$$

To reduce energy loss, the solar circuit supply pipes should be kept as short as possible. The low thermal mass of a HP-ETC causes it to absorb solar radiation and transmit heat quickly to the solar fluid. They also concluded that HP-ETCs are more efficient than flat plate counterparts when operating as components of a solar water heating system by comparison of study results.

Vishal Dabra, Laxmikant Yadav and Avdhesh Yadav et al [13] studied the effect of tilt angle on the performance of evacuated tube solar air collector: experimental analysis.

The Evacuated tube solar air collector is located at different collector tilt angles at 30° and 45° with the horizontal. Tilt angle played significant influence on the thermal performance of the evacuated tube solar air collector along with or without reflector. For 30° tilt angle evacuated tube solar air collector with reflector had better thermal performance than the 45° tilt angle evacuated tube solar air collector with or without reflector. Increasing collector tilt angle had no positive effect on the thermosyphon phenomenon inside the evacuated tubes.

They concluded that thermal performance of evacuated tube solar air collector at 30° tilt angle had more than at 45° tilt angle with and without reflector. They noted that steep collector tilt angle (45°) decrease the thermal performance of evacuated tube solar air collector and the thermosyphonic circulation phenomenon.

Hongfei Zheng, Jianying Xiong, Yuehong Su and Haiyin Zhang et al [15] studied the influence of the receiver's back surface radiative characteristics on the performance of a heat pipe evacuated tube solar collector.

There is a significant influence on the performance of a heat pipe evacuated tube solar collector of receiver's back surface radiative characteristics. This influence is generally related to the back surface emissivity and temperature. The heat loss of the evacuated tube collector increases with the increase of the back surface emissivity. The change of back surface emissivity can significantly affect the performance of the ETSC at higher temperature but affect little at lower temperature. The treatment on the receiver's back surface may solve the overheating problem of ETSC in summer by increasing the receiver's back surface roughness.

Heat transfer model of ETSC suggested by author is as shown in figure given below.

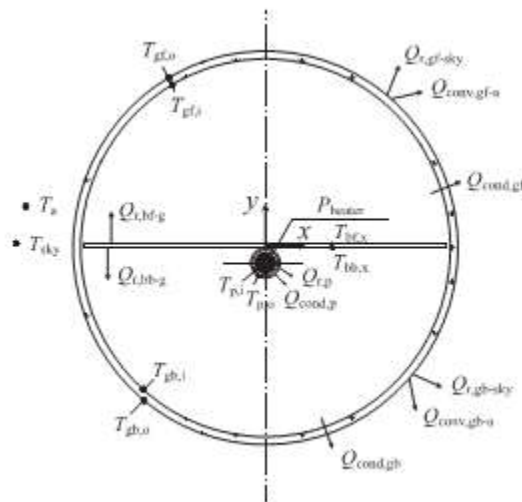


Fig.18. Heat transfer model of the ETSC

They mainly focuses on studying the methods of increasing or decreasing the heat loss of ETSC by changing the receiver's back surface emissivity and studied that by performing roughness treatment on the receiver's back surface. One can increase the emissivity of evacuated tube collector and the radiative heat loss can be reduced by adding sunshade plate.

The influence of the receiver's back surface emissivity, on the heat loss is more significant when the temperature is higher, while the effect is very limited when the temperature is in lower range.

4. CONCLUSION

L.M. Ayompe, A.duffy, M.conlon and S.J.McCormack et al [8] investigated comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCS) for domestic water heating systems in a temperature climate. They presented a year round energy performance monitoring results of two solar water heaters with 4 m² flat plate and 3 m² heat pipe evacuated tube collectors (ETCS) operating under the same weather conditions. They concluded that the 4 m² FPC system compares quite favourably with the 3 m² ETC system when connected to a 300l hot water tank.

Boris Rassamakin, Sergii Khairnasov, Vladilen Zaripov, Andrii Rassamakin and Olga Alforova et al [14] investigated aluminium heat pipes applied in solar collectors.

Metal heat pipes applications to liquid solar collectors, especially to evacuated glass tube ones, is an efficient solution for water heating plants. Still majority of thermal solar collectors can't fulfil the requirements such as small weight, easy assembly and installation, versatility, scalability and adaptability of design. There are also some problems in liquid solar collectors such as very high hydraulic resistance and low thermal efficiency less than 0.5. Authors are proposing to apply extruded aluminium alloy made heat pipe with wide fins and longitudinal grooves to avoid the drawbacks of liquid thermal collectors.

They concluded that axial grooves can enhance heat transfer inside the heat pipe similar to a wick. The developed solar collector had very high modularity and scalability.

They also noted that thermal performances of developed solar collectors are note worse than those of the compared ones without heat pipes or made of copper with high thermal conductivity. Also it had very low hydraulic resistance.

After reviewing such number of papers we reach on the conclusion that evacuated tube collector with heat pipe technology has best performance among all and also there is some improvements needed to increase the performance of evacuated tube solar collector. So, we are using evacuated tube solar collector for hot water generation which is required in refrigeration system used for horticulture product.

Acknowledgements

Firstly I would like to express my sincere gratitude to my advisor Prof. Kedar Bhojak sir for the continuous support of my M.E. study and related review, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing this review. I could not have imagined having a better advisor and mentor for my M.E. study.

Besides my advisor, I would like to thank the rest of my review committee:

Prof.A.M. Mavani and Dr. A.R. Patel, because of their insightful comments and encouragement, but also for hard question which incited me to widen my research from various perspectives.

My sincere thanks also goes to Dr. M.Shyam, Mr. Asim Joshi, Mr. and Sampath Kumar, who provided me an opportunity to join their team as intern, and who gave access to the laboratory and research facilities without their precious support it would not be possible to conduct this research.

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