A Study and Theoretical Analysis of Evacuated Tube Collectors as Solar Energy Conversion Device for Water Heating

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Abstract - Energy is one of the basic and essential requirements of livinghood. In present scenario we are dependent on conventional energy sources for producing energy to sustain our lives. Since these sources are depleting at faster rate and cost of energy is increasing simultaneously, so conversion of renewable form of energy is much desired now. Most of energy that we are using is non-renewable resources which increase the pollution and amount of CO_2 in environment so it required using renewable and clean energy. And solar energy is good option for that it is in use also. The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 having approximately 2,300–3,200 sunny hours per year, depending upon location. Raipur is located in the sunny belt of the country and receives a good amount of solar radiation over the year. It has been observed that the daily global solar radiation over the Raipur's region is 4.58 kwh/m^2, while the daily diffuse radiation is 1.72 kWh/ m^2.Solar radiation which we receive as heat and light can be converted to useful thermal energy or for production of electricity either through solar photovoltaic route or through solar thermal route. In this study devices for converting solar energy in to some other kind of useful energy e.g. for the purpose of water heating etc. is discussed and thermal analysis of efficiency is presented with its pay-back period.

Index Terms—Energy, Evacuated tube, Solar energy, Water heating

I. INTRODUCTION

Energy is one of the basic and essential requirements of living beings. Since the conventional energy resources are fast depleting and cost of energy is increasing, it is very important to conserve energy. Most of the power is produced by the use of fossil fuels, (like coal, oil gas etc.) which emit tons of carbon dioxide and other pollution every second and more importantly, the current trend is signifies that the world is losing all its fossil fuels at a rapid pace. The main solution to get rid of this problem is to effectively make use of the Renewable Energy Sources available around us. India is largely located on the earth's equatorial sun-belt and thus receives abundant radiant energy of sun. India is receiving about 5,000 trillion kWh/year equivalent energy through solar energy. India has clear sunny weather about 250 days to 300 days in year. The annual global radiation varies from 1600 kWh/m^2 to 2200 kWh/m^2 and this corresponds to the tropical and sub-tropical regions. The average solar insolation incident over India is about 5.5 kWh/m^2 per day. Just 1% of India's land area can meet India's entire electricity requirements till 2030 [15].

Solar-based power technologies are an extremely clean form of generation with practically no form of emissions at the generation point. These options have potential to lead towards energy security through displacement of coal and petroleum.

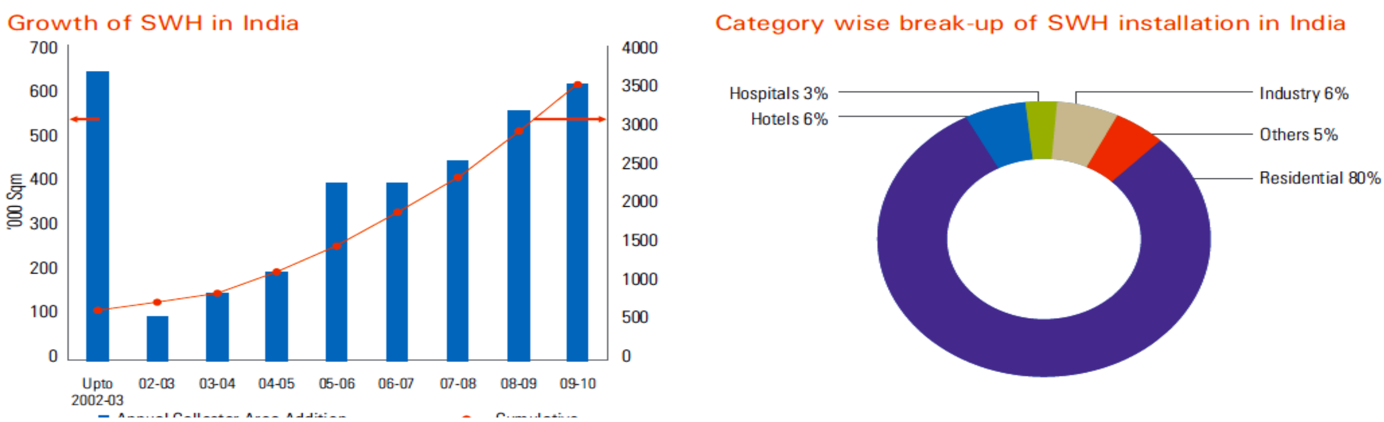

Fig-1 Market of solar water heating in India [8]

India is a tropical country, where sunshine is available for longer hours per day and in good intensity. Therefore, solar energy has great potential as future energy source.

II. ENERGY REQUIREMENT

India is fifth largest country in world for power consumption, but still requirement of more power production. As on 31th Jan 2013 our country installed 211,766.22 MW plant in which most of production based on thermal means uses of coal (almost 57%) and resources are in less quantity. Following table gives the idea of fuel use for power generation (in %) [1]

Total Capacity	2,11,766.22
Coal	57.44%
Hydraulic	18.61%
Res	12.20%
Gas	8.92%
Nuclear	2.25%
Oil	0.56%

Table-1 Energy requirement in Country

These are the capacity of plant use different types of fuel for power generation. Most of power generation take place of coal, due to which % of CO_2 increases in atmosphere causes increases in temperature. So renewable energy sources (RES) should use for power generation or for other uses.

III. RENEWABLE ENERGY SOURCE

Renewable energy is generally defined as energy that comes from resource which are natural [2]. Such as solar energy, wind energy, tidal energy, waves energy etc. These energy can utilised for different purposes, especially solar energy. Solar energy is used for following purposes for heating & power generation, for cooking etc. Solar energy is one of the cleanest energy resources. The usage of solar energy is not only beneficial to preserve the natural environment of our world, also the easily attainable and most economically motivating of all the other forms of energy.

A. Benefits of Using Renewable Electricity [4]

Reduction in emission

-750–1000 tons of CO_2, 7.5–10 tons of SO_2 3–5 tons of NO_x

-50,000 kWh reduction in energy loss in power lines and

-Minimal capital cost and lower capacity equipment can be used (such as transformer capacity reduction of 50 kW / MW installed).

Globally, the industries of solar evacuated tube collectors are growing at 15% annually [5]. India accounts for around 1.5% of the total installed capacity and 1% of the sales during 2008.

IV. SOLAR ENERGY

Solar energy is define as radiated light & heat from the sun. The sun is a large spherical mass of very hot gases, and the heat is being generated by various a kinds of fusion reactions and it is the ultimate source of all energy and radiating energy of 3.841×10^{17} watts. Using a range of ever-evolving technology such as solar heater, solar thermal electricity solar architecture etc. Solar technologies are broadly characterized as either passive or active solar depending on the way they receive, convert and disperse solar energy. The sun radiates energy uniformly in all directions in the form of electromagnetic waves and the sun provides the energy needed to sustain life in our solar system. It is clean, inexhaustible, abundantly and universally available source of renewable energy and the major drawback of solar energy are that it is a dilute from of energy, which is available intermittently and uncertainly, and not steadily and continuously.

A. Uses of Solar Energy

It can be used as many domestic and industrial purpose; such as water heating, solar cooking, irrigation purpose, cooling, space heating, drying purpose for both industrial and domestic sectors and also for electricity generation(solar photovoltic) purpose it is used.

Figure-2 share of appliances [8]

Active solar techniques include the use of photovoltaic panels and solar thermal collectors and the passive solar techniques include selecting materials with favourable thermal mass or light collecting characteristics. Due to change in the extra-terrestrial radiation normally incident solar radiation received by the earth's surface is subjected to vary. The solar radiation average density above the earth's atmosphere in a plane perpendicular to the rays is 1353 W/m^2 [1].

B. Advantages

1. Solar energy is free of cost
2. It does not cause any pollution
3. Conversion devices for this does not make any noise
4. Maintains is low.
5. Solar power plant installation is very easy

C. Disadvantages

1. Initial Cost is slightly high.
2. Solar power cannot be harnessed effectively when sun is not present.
3. They cannot produce same amount of power for same capacity of power plan
4. Large area is required as compare to coal plant for same power generation.

V. CONVERSION DEVICE FOR SOLAR POWER

For conversion of solar energy into the useful energy the device is used is called photovoltaic device which convert the light into electrical direct current by taking advantage of the photoelectric effect. Solar photovoltic has the most potential to renew the solar energy. As Concentrated solar power concerns with PV technique, it uses lens or mirrors and tracking systems to focus a large area of sunlight into a small beam.

A. Solar cell-

A solar cell is a thin silicon disks which converted solar energy into electrical energy cell are also called as photoelectric cell or photovoltaic cell. This cell used is various calculator, roof-mount panel etc. When light falls on the cell subatomic absorb it & electron start flow this is called as electricity is generated [4].

Fig-3 A 14 MW Power Plant in Nevada, USA Installed in 2007

VI. CONVERSION DEVICE FOR SOLAR THERMAL

Basically solar thermal conversion device are following type-

1) Flat plate solar collector
2) Evacuate tube solar collector [5]

A. 1. Flat Plate Collector

Flat plate collector are in wide use for domestic household hot water heating & for space heating where the demand temperature is low. Many excellent models of flat-plate collector are available. A discussion of flat-plate collector is supply low temperature demands or to preheated the heat transfer fluid before entering a field of higher temperature concentrating collector.

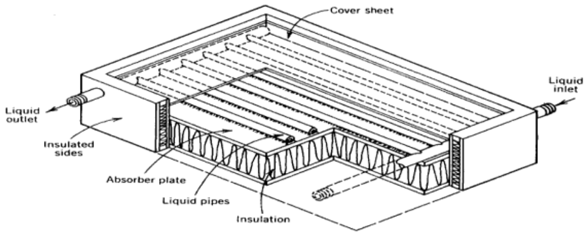

Fig-4Schematic view of flat plate collector [8]

2. Specification Of Flat Plate Collector System [16]-

Element	Material	Size and Particulars
Absorber Material	Copper - Copper absorber	
Fins	Copper	9 No's
Header Tubes	Copper	Ø25 mm, 22 SWG
Riser Tubes	Copper	Ø12.5 mm, 24 SWG
Header Protective coating	Polyurethane coating	
Riser to Fin Joining	Ultra Sonic Metal welding	
Collector Box	Aluminium	
Protective coating on Collector Box	Pure Polyester powder coated - Golden Yellow	
Glass retaining angle	Pure Polyester Powder coated - Black	25 mm
Collector back sheet	Aluminium Screwed to the frame	
Back, Corner Sealing	Non Acidic Silicon sealant through corners and screw joint	
Top Cover/Glazing	Toughened glass	4mm thick
Absorber Flanges	Thick Machined brass flanges,	4 mm, 63 mm dia
Gaskets and Grommets	High quality EPDM special shaped full Gaskets and Grommets	
Insulation Bottom	Rock wool,	50 mm 48 kg/m³ density
Insulation Side	Rock wool,	25 mm 48 Kg/m³ density
Reflective foil	Aluminium	50 microns thick bottom, 0.45 mm sides
Collector Supports	Fabricated and Duly powder coated Mild Steel Sections	

Table-2 Specification of material and component of flat plate collector

3. Working Of Flat Plate Collector System

A flat-plate collector consists of transparent cover, absorber, a frame and insulation. Usually a low iron safety glass is used as a transparent cover as it lets trough a great amount of the solar radiation. Only very little of the heat emitted by the absorber escapes the cover and this effect is known as greenhouse effect. The transparent cover prevents the absorber from wind cooling. The cover protects absorber from adverse weather conditions.

The insulation on the back of the absorber and on the side walls reduces the conduction heat loss. Insulation on better quality panels are usually mineral fiber insulating materials like glass wool or rock wool. The carrier fluid (usually water or glycol) to absorb heat flows through a pipe, which is connected to the absorber strip made of copper or aluminum. Absorbers designed usually black, as dark surfaces absorb the solar radiation in good quantity. As absorber surface warms up to a temperature higher than the ambient temperature, it gives off heat to fluid flowing through it. Then circulation of water is may be forced or free.

B. 1. Evacuated Tube Collector

In an attempt to get a higher-performancesystem they are made from glass tubes with the enclosed space sealed and annulus space being negative pressure. They are designed to have very low overall heat loss when operated at higher temperatures. Due to single glazing and with evacuated space these collectors have lesser convective loss. [5]

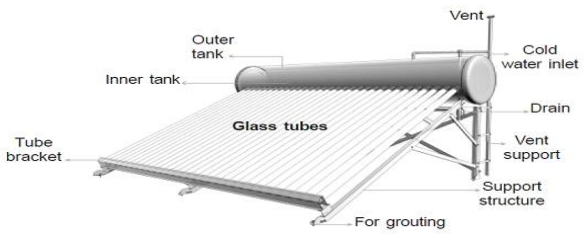

Fig-5 General Set-up of Evacuated tube Collector water heating System

1. Description Of Evacuated Tube Elements

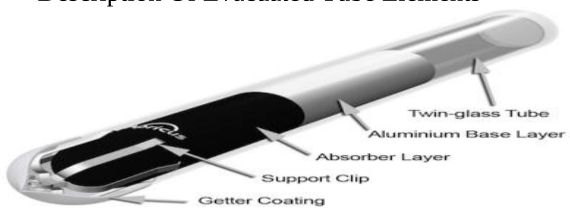

Fig-6Elements in evacuated tube collector [7]

Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass with high chemical and thermal shock resistance. The outer tube is transparent allowing light rays to pass through with minimal dispersion. The inner tube's outer surface is coated with a sputtered solar selective coating (Al-N/Al or AlN/AlN-SS/Cu) which features excellent solar radiation absorption and minimal reflecting characteristics. The open ends of the concentric tubes are fused together. Wind and low temperature have less of effect on the function of evacuated tubes when compared to flat plate solar collectors due to the vacuum insulating properties. During the vacuum creation, a Barium Getter is fixed into the base of the outer glass tube. The Getter centring is done at the inner glass tube. When the glass tubes are heated before the ends are fused together the Barium Getter also becomes very hot and emits a pure layer of Barium at the bottom of the tube which will look like a chrome plate on the inside of the outer glass tube. If in the future, the glass being damage, the shiny chrome look will change to a milky colour, thus, making it easy to check if the vacuum has been lost also a clear visual indicator of the vacuum status.

2. Working Principal Of Evacuated Tube Solar Water Heating System-

A solar water heating system consists of a vacuum glass tube collector, an insulated storage tank and connecting stand parts. The evacuated glass tubes are filled with water and placed in open, starts heating the water in the glass tubes. Since the density of cold water is heavier than hot water, it starts rising in the insulated water tank, and the cold water sinks into the glass tubes. On cycle repeatation, water heats up, known as thermo-siphon and is based on natural convection. The storage tank is insulated so the water stays hot and can be used later in the day.

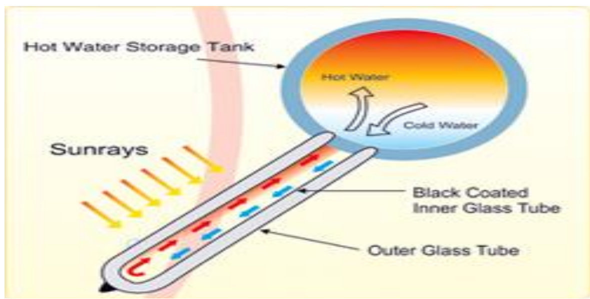

Fig- 7Working principal of evacuated tube collector WHS

VII. TYPES OF EVACUATED TUBE COLLECTOR [3]

There are following types of evacuated tube solar collectors-

i) Water-in-glass evacuated tube collectors,

ii) Evacuated U-tube collectors,

iii) Heat pipe evacuated tube collectors,

A. 1. Water-In-Glass Evacuated Tube Collectors

Evacuated tubes are the absorber of the solar water heater and they absorb solar energy converting it into heat for use in heating water. Evacuated tube consists of two glass tubes made from extremely strong borosilicate glass. The outer tube is transparent to allowing light rays to pass through with minimal reflection and the inner tube is coated with a special selective coating (Al-Nickel/Al) which features excellent solar radiation absorption and minimum reflective characteristics. The free end of tubes are fused together with each other and the air contained in the space between the two layers of glass is pumped out to expose the tube to high temperatures. This vacuum plays an important role in the performance of the direct flow evacuated tubes.

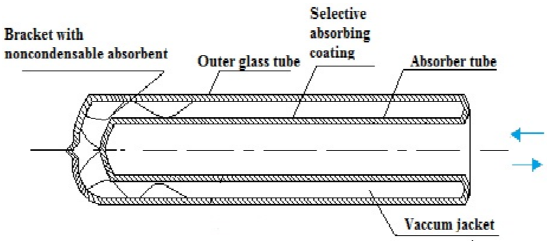

Fig-8Axial structure of evacuated tube collector

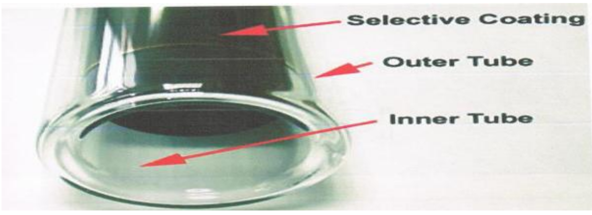

Fig-9 Water-in-Glass Evacuated Tube Collector

The figure depicts the structure of evacuated glass tube, which has concentric tubes and with vacuum between the walls. The vacuum acts as perfect insulator and does not allow short wave radiations to escape through the glass tubes. Vacuum's characteristics regard of trapping solar radiation much more effective and hence an appreciable high efficiency of collection can be achieved. A stable supply of heat to the manifold at intermittent weather is possible. The tube will provide heat continuously even after the sun has set down up to certain time.

2. Evacuated U-Tube Solar Collector

The construction of evacuated U-tube collector is almost same to that of water-in-glass collector except a circular fin to store heat and to conduct collected heat and a U-tube of copper element. The working of evacuated solar water heater is based on a natural circulation of water within the system. The Principle is called 'Thermo syphon' the key important point of these systems is that: the evacuated tube solar collector is always tilted a little because straightness of tube would not let flow of water within the tube. As the sun rays pass through outer glass tubes they are largely transmitted directly to the inner glass tubes due to vacuum presence. The inner glass tube outer surface is coated with heat absorbing coatings. Thus radiations are absorbed by the selective coating and gets collected in to thermal energy and transfer of heat to the water take place by means of convection. The water temperature in tubes rises making it less dense or lighter and hot and lighter water naturally moves up to the top of collector and through the evacuated collector tube goes to the outside and stored. Simultaneously the higher dense water through U-tube runs to bottom. The movement continues due to density change till the homogeneity in temperature is not achieved.

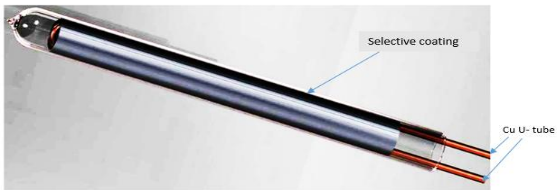

Fig-10 Evacuated U-tube Solar Collector

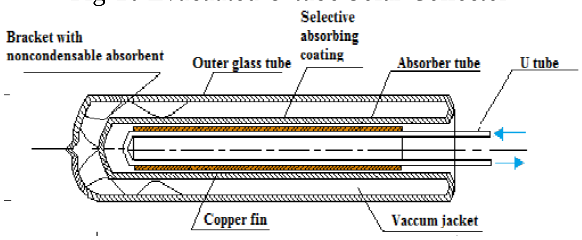

Fig-11 Axial structure of Evacuated U-tube collector

Technical Specification of Various Element of Evacuated U-Tube Solar Collector [5]-

Material	**Parameters**	**Size and Particulars**	**Unit**
Outer glass tube	Thickness Diameter Conductivity Transmissivity Refractive Index Length	2 47 0.74 0.92 1.474 1500	mm mm w/m k - - -
Inner glass tube	Diameter Thickness Conductivity	37 2 0.74	mm mm w/m k
Copper tube	Thickness Diameter Conductivity	0.7 8 398	mm mm w/m k
Absorbing coating	Absorptivity Emissivity	0.92 0.08	- -

Table-3 Specification of evacuated U-tube collector

3. Heat Pipe Evacuated Tube Collectors

A heat pipe evacuated tube collector consists of a heat pipe inside a evacuated tube. The vacuum envelope retards convection losses greatly and conduction losses which helps it to operate at higher temperature. Heat pipe consists of a hollow copper pipe with larger diameter blub at one end. A small amount of high purity of liquid water is added into the heat pipe and it is heated to high temperatures to evacuate any air from within the space. Heat pipes ensure one-way heat transfer from the absorber to the water. In the inner cover of the evacuated tubes the selective coating ensures high energy absorption and low emission losses. The liquid in the inner glass heat pipes changes into vapour which then rises up in heat pipe. When thermal energy is transferred between the condenser end of the heat pipe and the cold water in the tank, it turns into liquid again, and comes down to the base of the pipe and cycle repeats as long as the sun shines. Hot water can be obtained by injecting cold water into the bottom of the tank, with the hot water being forced out the top. The evacuated tubular collector with heat pipes are quasi-tracking. The solar water heater can be in service all year round even in cold climate areas since heat pipes transfer heat in one direction only within the collector and the vacuum prevents convective heat losses. In heat pipe ETC the tubes are mounted with the metal tips projecting into heat exchanger (manifold) containing flowing water and the heat is transferred into the main foiled through circulation pipe work. The heat pipe evacuated tube collector diagram is shown in below figure

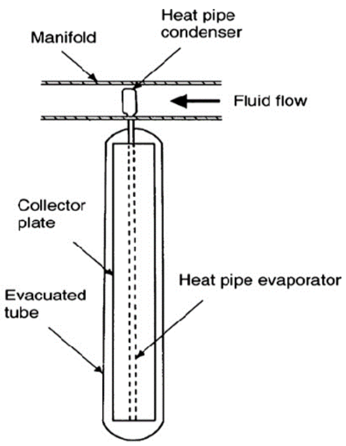

Fig-12 Heat pipe evacuated tube collector [10]

B. Advantages Of ETC:

1. It can be used in any climate, from extremely hot to extremely cold weather.
2. Its high level of vacuum ensures the operation under cold weathered conditions.
3. Evacuated tube solar collectors require lesser space and it is very easy to install.
4. Heat loss in the day time is negligible for evacuated tube collector.
5. It can absorb the solar radiation from multiple angles, due its tubular design.

C. Limitations of ETC:

1. Initial cost is high as compared to other collectors.
2. Construction of Evacuated U-tube Collector is little bite complicated as compared to other collectors and thus proper handling required.
3. Some-times due to improper handling and maintenance temperature becomes very high due to lack of water in the tube and hence it causes a thermal shock so tube may crack and resulting vacuum to loose.

The governing parameter of system success is its efficiency. The efficiency of solar collectors for either solar thermal or solar power depends upon following main parameter-

1. Solar radiation of location,
2. Atmospheric temperature,
3. Absorbing Coating,
4. Material,
5. Tilt angle,
6. Facing (north phasing or south phasing),

D. Application of ETCSWH

Solar water heating systems are most likely to be cost effective for operations such as laundries or kitchens that demands large hot water volume. Applications of Evacuated U-Tube Solar collector are as listed below:

- In industrial field e.g. power plant, steam power plant, in school and hospitals.
- In laundries, in space heating. Generally used in northern countries for heating purpose of water like swimming pool as per the season.
- It used for domestic purpose e.g. electricity, water heating, and in kitchen stuff.

VIII. THERMAL PERFORMANCE ANALYSIS-

Performance analysis of solar collector systems is done by taking suitable test procedures and assumptions. According to ASHRE or EU standards, collector thermal performance tests can be considered in three parts. The first is to determine the efficiency with beam radiation. The second is to determination of effects of angle of incidence of the solar radiation. The third is to determine collector time constant, a measure of effective heat capacity [Duffie & Beckmen, 1980]. The basic method ofmeasuring collector performance is to expose the operating collector to solar radiation and measure the fluid inlet and outlet temperature.

Few assumptions made to simplify the analysis are-

- The averaged heat flux along the circumferential direction is assumed [21].
- The heat transfer process is assumed to be steady [20, 23].
- The conduction from the glass tubes walls through the structure that supports them is very small thus effect has been assumed to be neglected.

Equations to govern the system performance of the above mentioned collectors are presented here.

A. For Water-in-glass-

The quantity of heat obtained by ETC can be calculated by formula (Huanxia, 1997):

$$\mathbf{Qy = d \times L \times 16 \times F_R \times [I_{eff} - \pi \times U_L \times (T_{f,i} - T_a)]}$$

where d is the external diameter of inside glass tube, m; L is the length of glass tube, m; F_R is the heat removal factor; I_{eff} is the collected heat by tube per unit area per unit time, w/m^2; U_L is the heat loss coefficient, w/(m^2 ^oC); $T_{f.i}$ is the inlet temperature of collector, ^oC; T_a is the monthly mean temperature of the air, ^oC.

Also using this equationthe collected energy by the collector tubes under steady states can be obtained [14]-

$Q_u = m. C_p. (T_{fo}- T_{fi})$

And the collection efficiency is defined as the ratio of energy absorbed by the fluid to the total flux incident on the tilted surface of the collector before transmission losses-

$$\eta = \frac{m\ C_p\,(T_{f,o} - T_{f,i})}{I.A_g}$$

Where,

I=Input solar energy

m = Mass flow rate of water

C_p= specific heat of water (joule/gram ^oC)

T_{fo} - T_{fi} = temperature difference (outlet fluid temperature-inlet fluid temperature) in ^oC

B. For Heat Pipe evacuated tube collector [15]-

Energy collected

The useful energy collected by the solar energy collector is given as (Kalogirou, 2009):

$Q_c = m. C_p\ (T_{c,o} – T_{c,i})$

Energy delivered and supply pipe losses-

The useful energy delivered by the solar tube with heat pipe to the water tank is given as

$Q_d = m. C_p\ (T_{sc,i} - T_{sc,o})$

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 water tank. The loss is calculated as:

$Q_L = m. C_p\ (T_{sc,i} - T_{sc,i})$

Solar fraction

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

$$SF = Q_s / (Q_s + Q_{aux})$$

Collector efficiency

The collector efficiency was calculated as (Sukhatme, 1998; Duffie and Beckman, 2006):

$$\eta = \frac{m\ C_p\,(T_{c,o} - T_{c,i})}{A_c G_t}$$

System efficiency

The system efficiency was calculated as (Sukhatme, 1998; Duffie and Beckman, 2006):

$$\eta = \frac{m\ C_p\,(T_{sc,i} - T_{sc,o})}{A_c G_t}$$

C. For Evacuated U-tube solar collector-

The thermal analysis of evacuated U-tube collector is followed by above mentioned general assumptions. To understand the useful heat gain and heat loss by collector a thermal network is presented. The resistances in the network represents the element of collector, as they offers some resistance to radiation/heat flow.

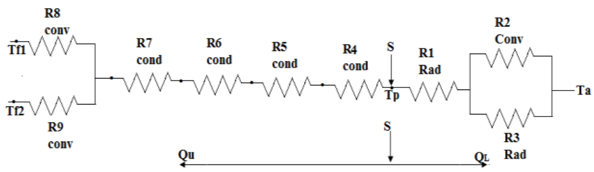

Figure-13 Thermal network of evacuated U-tube solar collector

Using this thermal network the heat loss coefficient for collector can be written as-

The overall loss coefficient can be defined as [21]–

$U_L= U_t+U_e$

Where U_e is edge loss coefficient of the header tube, which depends on the insulation conductivity, insulation thickness and the surface area of the header tube. In the present analysis of collector a single tube is taken at no draw-off condition with open end closed and U-tube filled with water. Therefore value of U_e is assumed to be neglected.

The heat loss coefficient U_L is calculated from thermal resistance between the absorber tube and the outer glass tube and between the outer glass tube and the surrounding air such that:

$$U_L = \frac{1}{\frac{1}{h_{rad,og} + h_{wp}} + \frac{1}{h_{rad,ig}}}$$

Where:

$h_{rad,og}$ is the radiation heat transfer coefficient of the outer glass tube.

h_{wp} is the adjusted convection heat transfer coefficient of the outer glass tube.

$h_{rad,ig}$ is the radiation heat transfer coefficient of the inner glass tube.

Radiation from the Outer Glass Tube

The radiation loss from the outer glass tube surface accounts for radiation exchange with the sky [16] at temperature, T_s. For simplicity, it is referenced to the ambient air temperature, T_a so that the radiation heat transfer coefficient from the outer glass tube surface can be written in following equation

$$h_{rad,og} = \varepsilon_{og}\sigma \times \frac{T^4{}_{og} - T^4{}_{s}}{T_{og} - T_a}$$

Where:

$\varepsilon_{og}$is the emissivity of the outer glass.

σ is the Stefan –Boltzmann Constant (5.6697×10^{-8}) $W/m^2.K^4$

$T_{og}$is the temperature of the outer glass tube, K

T_a is the ambient temperature, K

$T_s$is the equivalent sky temperature as a function of the ambient air temperature, K.

Sky temperature to the local air temperature [14] in the simple relationship shown below-

$T_{sky} = 0.0552 \times T_a^{1.5}$

For each outer glass tube the actual radiating surface is equal to its surface area, but in fact, heat radiated only to the front.

Outer Glass Tube Convection

The wind loss coefficient or adjusted convection heat transfer coefficient h_{wp} of the outer glass tube surface is approximated by heat transfer coefficient around the outer glass tube.

The wind loss coefficient [18] is:

$$h_{wp} = \frac{A_{og}}{A_{ig}} \times 0.6 \times h_w$$

Expression for h_w, for single tube, have been determined from data illustrated by Holman [17]. For the case of natural convection heat transfer above Equation is used.

$h_w = 5.7 + 3.8\, V_w$

Where:

h_w is convection heat transfer coefficient around the outer glass tube,

V_w is the wind speed (m/s).

The value of h_w represents the loss per unit area of the outer glass tube surface.

Radiation between Absorber Glass Tube to the Outer Glass Tube

The coefficient of radiation heat transfer between the absorber tube and outer glass tube [18] can be written as: $h_{rad,ig} = \varepsilon_{ig} \times \sigma \times \frac{(T^4{}_{ig} - T^4{}_{og})}{(T_{ig} - T_{og})}$

Where,

$T_{ig}$is Temperature of absorber tube [21, 25] and it is calculated equal to 413 K

ϵ_{ig} is the emissivity of the inner glass.

T_{og} is Temperature of outer glass tube and it is measured by thermocouple equal to 305 K,

The useful Heat Gain (Q_u)

The useful heat gain by working fluid [25] is given as follows-

$Q_u = A_c F' [I (\tau_g.\alpha_g) – U_L (T_F – T_A)]$ watt

Where, A_c = Area of collector and F' = collector Factor = 0.9 [21]

Collector Efficiency, η

The thermal performance of evacuated tube solar collector can be estimated by the solar collector efficiency, η, which is defined as the ratio between the net heat gain and the solar radiation energy [21, 26, 27].

$\eta = \frac{Q_u}{I.A_c}$

Where A_c is defined as-

$A_c = \pi DL$

Where D is the outer diameter of absorber tube and L represents thelength of absorber tube.

Since F', (ατ) and U_L are constant [23], therefore,

$$\eta \alpha\ (T_f - T_a)/I$$

The experiment conducted from January 2014 to February 2014 at Raipur Institute of Technology, Raipur, CG (longitude=81° 41' E, latitude=21° 15' N), which had Sunny day, moderate climate and partially cloudy some times. Throughout the testing period, the collector faced south at a tilt angle equal to latitude of Raipur.

IX. ECONOMIC ANALYSIS & PAY-BACK TIME CALCULATION

Assuming System Details - 100 liters per Day;

Collector area-1.10 m^2;

Considering Atmospheric Temperature= 20^oc.

Heat gained by water = m C_pdT

= 100 × 4.12 × (80-20)

= 24720 KJ per Day

Electricity required

Here, 1 kWh = 3600 kJs,

Assuming electric heater efficiency =80 %,

Thus, electricity unit required = 24720/3600

= 6.86 unit per day.

Electricity consumed = 6.86/0.8

= 8.58 unit per day.

Cost of electricity = 8.58 unit × Rs. 3.50 per day.

@ Rs. 3.50 above 300 unit consumption by monthly,

@ Rs 3.50/ unit is taken from household electricity bill of Chhattisgarh state,

Cost of electricity = Rs.30.3 per day. (Taken Rs 30)

Cost of electricity = Rs. 30 ×300 day

Consider 300 effective days per year [15]

= Rs. 9000/year.

Saving per year = Rs.9000/year,

Now,

Cost of 100 LPD Water-in-glass solar water heating systems is Rs. 17000.00

Payback period = (Cost of thy system + plumbing + installation) / saving per year

$$= \frac{17000}{30}$$

Payback period (in day) = 566.66 = 567 days

or

Payback period (in year) = 1.88 year

Conclusion may draw from above result that investment will be recovered in 567 (sunny) days and after that it is totally free. We can save approximately 9000 Rs per year and more when cost of electricity increases.

In similar manner pay-back period for evacuated U-tube collector is calculated 1.96 year and saving around 11265.63 rs per year based on the useful heat gain value and the price of collectors. For heat pipe evacuated tube collector the pay-back ranged between 1.5 years to 3 years for Raipur climatic condition.

X. RESULT

The present study of evacuated tube solar water heating system report that the trend of using power efficient device will be rapidly growing in coming decades. This analysis of energy consumption by mean of water heating is estimated also Evacuated tube water heater. Comparison of analysis data and experimentally reported that Evacuated U-tube water heating system is much efficient around 10% to 15% than the water-in-glass evacuated tube collector for above mentioned climatic condition. The result of efficiency difference shows that the circular copper fin's heat capacity in evacuated U-tube collector leaded the efficiency up to 74% where as in water-in-glass evacuated tube collector up to 66%. We can use aluminium fin also in place copper fin but copper has better heat retaining properties. The payback period is calculated and found that after 567 days all investment comes back and it becomes free and saving of around 9000/- Rs per year can achieve. The evacuated U-tube collector's output temperature can use for Raipur (C.G.) climatic condition for house hold uses. The maximum temperature obtained was 97.5 ^{0}C for January 15th, which was clear sky day. Thus it can be used also in industrial application to generate steam for rice mill, power plants etc.

XI. CONCLUSION

The evacuated tube solar water heating device is one of the efficient way for house hold purpose not because of it is efficient as compare to other mean of water heating devices but also it is eco-friendly and non-polluting device. It's requited only one time investment the after certain time period it is does not required any charges for outcome (except maintains which is almost negligible). It returns your money in 567 sunny days, and next 20 years it will be free. This is a step towards reducing pollution free environment.

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