SOLAR THERMAL AEROGEL RECIEVERS IN SOLAR HEATERS

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ABSTRACT

Solar energy recovery has begun to take its place all over the world on the energy market due to the pureness of its electricity production. Commercial use of solar energy is unfortunately still rather small, mostly due to high prices and low efficiency compared to other sources. Current solar thermal receivers are insulated with vacuum tubes. This technology replaces these vacuum tubes with silica aerogels. Silica aerogels have an intrinsic spectral selectivity that allows them to pass solar radiation yet trap infrared radiation. In this way, they are both optically transparent and thermally insulating. By controlling the pH and drying time during processing, the aerogel microstructure can be optimized for this application. Through this technique, 95.5% solar weighted transmittance and a heat transfer coefficient <7 W/m2K were demonstrated for an 8 mm thick aerogel between 400°C and 100°C. These properties were also retained after the sample was exposed to 400°C and >80% relative humidity for >100 hours. By reducing the thermal losses from the system, aerogels also reduce the amount of optical concentration required for a desired thermal efficiency, which is why LFRs can be used instead of PTCs. STAR is not be susceptible to loss of vacuum which decreases annual energy average exergetic efficiency. Also, the STAR design allows for operating temperatures comparable to PTC receivers with less concentration area, meaning less land usage without sacrificing significant efficiency.

Keyword*s—vaccum; aerogel; silica; radiation*

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1. INTRODUCTION

Solar energy is the energy generated from the nuclear fusion in a star; i.e. the sun. In the fusion process in the suns' core, energy is released. That energy travels through the layers of the sun until it reaches the surface of the sun, where light is emitted. Of the radiated energy that reaches the atmosphere is called the solar constant. Solar panels are made up out of solar cells that convert light, energy, to electricity and/or warmth. The amount of solar radiation provided by the sun compared to the consumed energy on the earth in one year is illustrated in Figure 1.1. This illustrates a very high solar radiation that ought to be used; as an alternate method for the fossil fuels used today. Depletion of conventional energy resources and its adverse impact on environment have created renewed interest for the use of renewable energy resources. As a result, considerable research and development activities have taken place to identify reliable and economically feasible alternate clean energy sources. Purpose of solar water heater is to convert the solar radiation into heat to satisfy energy needs but with some limitations it is economically feasible alternate clean energy sources. Purpose of solar water heater is to convert the solar radiation into heat to satisfy energy needs but with some limitations it is not being used on grid scale because of its poor efficiency and higher initial cost. So there is a requirement of advancement in the solar water heater using flat plate collector to overcome its limitations so that it can be used as a replacement of conventional heaters and power generation devices.Solar collectors are distinguished as low, medium, or high temperature heat exchangers. There are basically three types of thermal solar collectors: **flat plate**, **evacuated tube** and **concentrating**. Although there are great geometric differences, their purpose remains the same: to convert the solar radiation into heat to satisfy some energy needs. The heat produced by solar collectors can supply energy demand directly or be stored. To match demand and production of energy, the thermal performance of the collector must be evaluated. The instantaneous useful energy collected is the result of an energy balance on the solar collector.

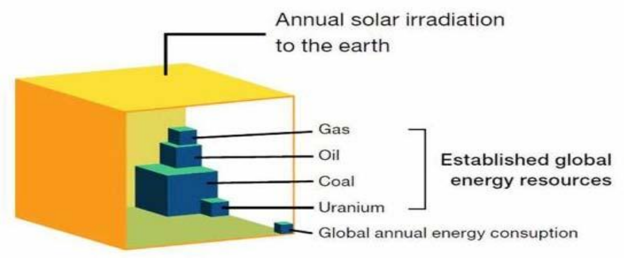

Fig 1.1: established solar aerogel design

A. Types of solar collectors

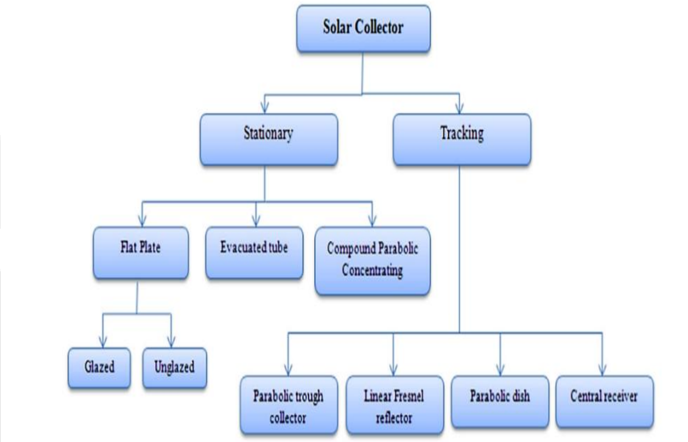

Fig 1.2: characteristics of a solar collector

2. COMPONENTS

A. Flat plate recievers

Solar collector is a kind of heat exchanger wherein heat exchange takes between a distance source and a heat transfer fluid flowing in the collector. Solar radiation from sun hits the absorber plate of the collector and the thermal energy is then transferred to the fluid. Based on their design, solar collectors can be classified as concentrating and non-concentrating type. Non-concentrating type can be further divided in flat plate collector and evacuated tube collectors. Flat plate collectors are the most common type of collectors and the most primitive too. Work of Hottel and Woertz in 1942 and by Hottel and Whiller in 1958 can be looked as a first work on solar flat plate collector. They had developed the collectors consisting of a black flat plate absorber, a transparent cover, heat transfer fluid and an insulating case. Maintaining the Integrity of the Specifications To increase the efficiency, it is very much important to decrease the heat loss from the collector. Many studies are oriented in this direction to study and reduce heat loss, with increased glazing, honey comb maze based absorber plate, considering wind velocity in analysis of collector etc. Analysing the performance of collector is equally important as it helps to further develop and improve the design. In fact, development and analysis always go hand in hand. Experimental analysis

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Structure of novel SWH

The novel FPC with MHPA absorber is the rectangular frame of the collector is 2000×1000×90mm. The top is covered by 3.2mm low iron tempered glass cover with solar energy transmittance of 92%. Spacing between the glass cover and the MHPA absorber is 30mm. The MHPA absorber is shown in. It is consisted of 32 MHPAs(930mm×60mm×3mm, 20% acetone working fluid), which is sprayed solar selective coating with 95% absorbility and 30% emissivity and closely arranged one by one. The small gap between the MHPA condenser and the top surface of water tube is filled with conductive grease, then connecting closely by riveting. A glass wool thermal insulation with a thickness of 60 mm is attached underneath the MHPAs and the water tube. The aluminum alloy frame is used to house all the parts of the collector. When it is in use, the MHPAs transfer the heat from its top surface to the water inside the water tube through the phase change of the working fluid. Owing to the special structure, the collector possesses the following advantages.

1) The MHPA has a good property of low temperature bearing (-100°C). The extruded-forming water tube provides strong pressure-bearing capability, which could bear temperature of -15°C when it is full of water, and could also easily drain down. Therefore, the MHPA absorber has a perfect frost-resistant character.

2) The contact thermal resistance between the MHPA condenser and water tube is smaller, thus its thermal transfer capability is improved.

3) Due to the MHPA with excellent isothermal characteristic, the MHPA absorber has uniform temperature field than that of the traditional one, thus the heat loss by natural convection in the air gap between the glass cover and the absorber is reduced.

The system is of no problem of water leakage because of no soldering on any part of the collector

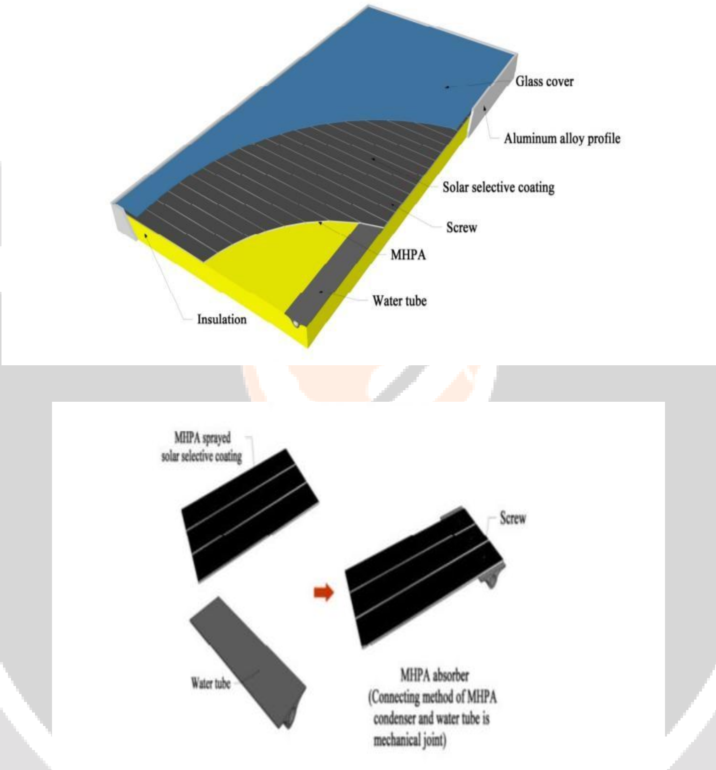

Fig 2.2: structure of novel SWH

Thermal performance is very much affected by heat losses from various sections. The upward region is totally exposed to environment and hence, heat lost from this region is significant. Heat lost is mostly through convection and radiation. Due to wind, the influence of convection is greater. Unglazed and single-glazed collector are affected to a great extent by these natural winds, and to compute their performance accurately, it is necessary to find the convective heat transfer coefficient due to winds. Many wind tunnel test has been performed in order to investigate this parameter, but as these collectors are always exposed to solar radiation and thus the natural winds, the actual affect may differ from that of wind tunnel.

3. EVACUATED TUBES

A variety of technologies exist to capture solar radiation, but of particular interest of authors is evacuated tube technology. Numerous authors have noted that ETSCs have much greater efficiencies than the common FPC, especially at low temperature and isolation. For instance, Ayompe et al. conducted a field study to compare the performance of an FPC and a heat pipe ETSC for domestic water heating system. With similar environmental conditions, the collector efficiencies were found to be 46.1% and 60.7% and the system efficiencies were found to be 37.9% and 50.3% for FPC and heat pipe ETSC, respectively. An ETC is made of parallel evacuated glass pipes. Each evacuated pipe consists of two tubes, one is inner and the other is outer tube. The inner tube is coated with selective coating while the outer tube is transparent. Light rays pass through the transparent outer tube and are absorbed by the inner tube. Both the inner and outer tubes have minimal reflection properties. The inner tube gets heated while the sunlight passes through the outer tube and to keep the heat inside the inner tube, a vacuum is created which allows the solar radiation to go through but does not allow the heat to transfer.

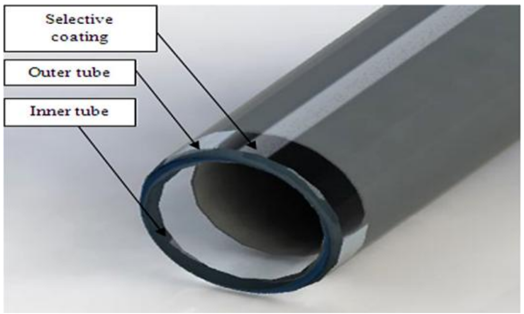

Fig 3.1: Evacuated tubes

A. Types of ETSC

According to Gao available types of evacuated tube solar collectors can be categorized into two groups; one is the single-walled glass evacuated tube and the other is the Dewar tube. There are many variations of the two basic types; for instance, heat extraction can be through a U-pipe, heat pipe or direct liquid contact. experimentally and numerically. Four different shapes are: finned tube (Model I), tube welded inside a circular fin (Model II), U tube welded on a copper plate (Model III) and U tube welded inside a rectangular duct (Model IV) . Firstly, by considering only the beam radiation, the performance of a single collector tube was observed and it was found that the incidence angle has great influence on the collector efficiency. Model III had the highest efficiency with small incidence angle but the efficiency of model II became higher than model III with the increment of incidence angle. The incidence angle has negligible impacts on collector performance

B. Dewar tubes

Dewar tube consists of inner and outer tubes which are made of borosilicate glass and selective absorbance is used to coat the outside wall of the inner tube to collect solar energy. The heat loss is reduced in by evacuating the layer between the inner and outer tubes. Tang investigated on dewar tubes and mentioned that the cheap price of dewar water in glass evacuated tube solar collector (WGETSC) makes it popular than dewar tube with U pipe evacuated tube (UPETSC) with heat pipe. Tian investigated the thermal performance of dewar ETSC with an inserted U pipe. Yan studied about the unsteady state efficiency of the dewar tube solar collector having heat pipe inserted. Xu tested the thermal performance of dewar tube solar collector under various dynamic conditions and they used air as the heat transfer fluid. Kim investigated the performance of dewar tube where the inner tube was filled with co-axial fluid and the outer tube was filled with an antifreeze solution and a one dimensional mathematical model was established.

4. DOMESTIC APPLICATIONS OF ETSC

a. Solar hot water

Since the last decade, the world market is rapidly growing for solar water heaters which results in large scale developments of improved quality products by various new technologies. A Solar water heater is a device for heating water by using solar energy to produce steam for domestic and industrial purposes. Solar energy comes from the sun in infinite amount as the form of solar radiation which falls on absorbing surface and then gets converted into heat which is used for water heating. When evacuated tube collectors are used to heat water, it is called evacuated tube solar water heater. There are various types of solar water heaters such as flat plate solar water heater, concentrated solar water heater and evacuated tube solar water heater.

b. Air Conditioning

Nowadays researchers are investigating environmental friendly technologies for air conditioning as producing electrical energy causes some pollution. Mehta and Rane investigated the liquid desiccant based air conditioning system which is adaptable to solar energy, a pollution free renewable energy source. The solar radiation is highly available in summer when the demand of air conditioning is also higher which makes it logical to use solar energy source for air conditioning. They developed a novel approach of using an ETSC with heat pipes as regenerator for a liquid desiccant based solar collector. They tested the collector at 100 ^{0}C to generate saturated steam which offers 51–60% efficiency for average 9 h. The average thermal COP of 0.82 was achieved as there is no heat loss to air and the power consumption was less than 40 W because of low pressure drop and flow rate of liquid desiccant collector. To increase COP by regenerating further, a liquid desiccant in low temperature stage which is possible by the latent heat produced in the ETSC was introduced.

c. Solar cooker

the thermal performance of a solar cooker based on ETSC with phase change material (PCM) storage unit. The prototype in was designed in two separate parts, one for energy collection and the other one for cooking. During sunshine hours, PCM stores solar energy which is used for cooking purpose at evening or night time. Different loads and loading times were used to conduct cooking at noon and evening and the evening cooking was not affected by noon cooking rather it was found to be faster as the heat in PCM storage was used.

5. CHALLENGES OF USING EVACUATED TUBE SOLAR COLLECTORS(ETSC)

d. Cost and maintenance

Morisson mentioned that the world market of solar water heater with ETSCs is significantly expanding due to the low cost manufacturing process of tubular solar collectors. According to China industry in 2001, about 65% of 6.5 million m^2 /year solar water heaters are double glass evacuated tubular solar water heaters. According to Mangal, evacuated tubes are strong and long lasting. In case if any tube is broken, it just requires replacing the broken tube which is cheap whereas for an FPC it is expensive as the whole collector is needed to be replaced. Arefin et al. did the cost analysis for a solar water heater and compared with the cost of an electric heater. They reported that the lifetime of a solar water heater is 30 years whereas the lifetime for an electric water heater is only 5 years.

e. Fragility

Evacuated tubes are made of two layers of annealed borosilicate glass and the glasses which are made of annealed glass are much more fragile than tempered glass. Because of fragility, glass tubes can be shattered easily due to small hail, jostling or poor handling. Therefore, extra care must be taken while transporting or handling ETSCs.

f. Snow removal

One of the characteristics of ETSCs is that they produce high temperature and get much hotter than other collectors. Therefore, ETSCs are not recommended for domestic solar water heating or for solar space heating system as the high temperature can cause significant problem when it exceeds boiling point of water; rather, it is recommended for commercial applications. For domestic use, it is essential to keep the temperature below 100^0C which continuously requires ample load on the system; otherwise weaknesses will be exposed in the material of evacuated tube due to overheating and eventually the vacuum will be lost.

6. PERFORMANCE BASED ON WORKING FLUIDS

To improve the efficiency of solar collectors, researchers have mainly focused on several structural changes such as changing the structure of solar collectors or changing the coating to improve absorptivity but from the literature, only few studies focused on changing the working fluid in order to improve the collectors' efficiency. From recent studies, it is found that the working fluid can influence the performance of solar collector significantly. Water, oil, and air are the most common working fluids used in solar energy system but the thermal conductivity of these fluids is relatively low. Recently, researchers are investigating on other working fluids such as nano fluids rather than water and air to improve the collector's efficiency. Nano fluids consist of base liquid and nano materials that have enhanced thermophysical properties such as higher thermal conductivity, thermal diffusivity and convective heat transfer coefficients. Besides improving the effectiveness of heat transfer, nano fluids also improve optical properties, transmittance as well as extinction coefficient of solar collectors. By using nano materials, the efficiency of an FPC has increased up to 10% and the incident radiation is found to be 9 times higher than a conventional FPC. For a direct absorption solar collector, the efficiency increased up to 10% using nano fluids

7. CONCEPT SOLAR RECIEVERS

For any solar receiver, the receiver efficiency is defined as the fraction of the incident sunlight on the receiver, Qs,rec, which is converted into heat and delivered to the thermal system below the absorber. Looking at the effective properties of the receiver as a whole, the efficiency can be expressed as:

$$\eta_{rec} = Q_h/Q_{srec} = (Q_{abs} - Q_{loss})/Q_{s,rec} = (Q_{abs} - Q_{loss})/CQ_{sol}$$

Where, Q_h is the delivered heat, Q_{abs} is the absorbed sunlight, and Q_{loss} is the sum of all the thermal losses. In the denominator, the solar flux on the receiver is represented as the product of the standard solar flux (e.g. the AM1.5 Direct + Circumsolar value of 900 W/m^2), Qsol 90, and an optical flux concentration ratio, C. The fraction of sunlight absorbed (and not reflected or scattered away) can be represented by an overall effective absorptance, $\boldsymbol{\alpha}_{eff} = Q_{abs}/Q_{s,rec}$; then equation 1 can be rewritten as:

$$\eta_{rec} = \boldsymbol{\alpha}_{eff} - (Q_{loss}/CQ_{sol})$$

8. MATERIALS REQUIRED

g. Silica

Silica aerogel is the most common type of aerogel, and the most extensively studied and used. It is silica-based and can be derived from silica gel or by a modified Stober process. The lowest-density silica nanofoam weighs 1,000 g/m^3, which is the evacuated version of the record-aerogel of 1,900 g/m^3.The density of air is 1,200 g/m^3 (at 20 °C and 1 atm). As of 2013, aerographene had a lower density at 160 g/m^3, or 13% the density of air at room temperature.

The silica solidifies into three-dimensional, intertwined clusters that comprise only 3% of the volume. Conduction through the solid is therefore very low. The remaining 97% of the volume is composed of air in extremely small nanopores. The air has little room to move, inhibiting both convection

h. Carbon

Carbon aerogels are composed of particles with sizes in the nanometer range, covalently bonded together. They have very high porosity (over 50%, with pore diameter under 100 nm) and surface areas ranging between 400–1,000 m^2/g. They are often manufactured as composite paper: non-woven paper made of carbon fibers, impregnated with resorcinol–formaldehyde aerogel, and pyrolyzed. Depending on the density, carbon aerogels may be electrically conductive, making composite aerogel paper useful for electrodes in capacitors or deionization electrodes. Due to their extremely high surface area, carbon aerogels are used to create supercapacitors, with values ranging up to thousands of farads based on a capacitance density of 104 F/g and 77 F/cm^3.

9. DESIGN OF SOLAR HEATERS

i. 2D Drawing of Solar heater

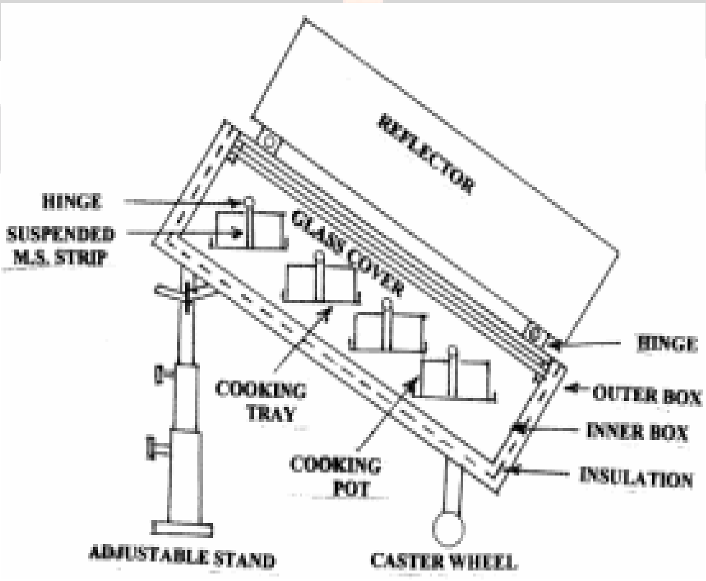

Fig 9.1: 2D drawing of the solar heater

j. 3D Drawings of Solar heater

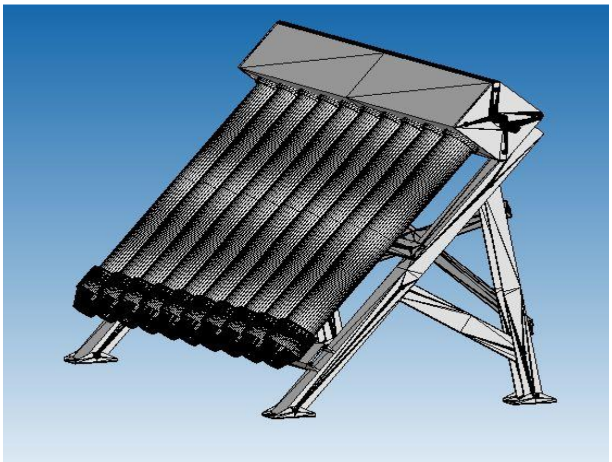

Fig 9.2: 3D Drawings of Solar heater

10. MESHED MODEL

The equations are an exception to the prescribed .STEP file is imported in ANSYS FLUENT 17. Where the mesh is generated. Part names are is given in this stage.

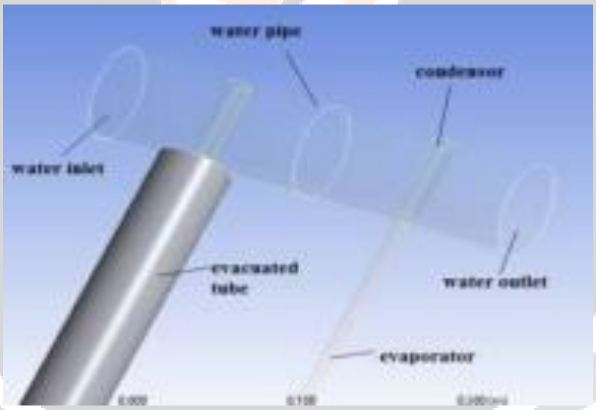

Fig 10.1: Meshed model

k. Meshing data

- Type of element: Hexa
- Method used: Multizone meshing
- Element size:
- Evacuated tube: 0.015
- Heat pipe: 0.003
- Water pipe: tetra-0.007
- Meshing result data:
- Number of nodes: 75,718
- Number of elements: 1,12,274

l. Fluent data

Mesh file is opened in FLUENT setup. Here the solver setting and boundary conditions are applied.

Models:

- Energy equation: on
- Viscous model: k-epsilon, RNG, standard wall function

Cell zone conditions: here we have assigned fluids for domain

- Evacuated tube: air
- Water pipe: water-liquid
- Evaporator & condenser: We are going to compare the effect of two different fluid on output temperature
  - water-vapour (conventional)
  - Nanofluid (Al_2O_3+ water)

Properties of water vapour are available in fluent database.
The thermophysical properties of nanofluid for a volume concentration of ϕ were calculated at the average bulk temperature of the nanofluid using the regression correlations widely used in the literature.
The density of Al_2O_3 nanofluid ρnf was determined using Pak and Cho's equation

$$\rho\mathrm{nf} = \phi.\rho s + (1-\phi)\rho$$

The effective thermal conductivity of dilute nanofluid k_{nf} can also be evaluated using the Maxwell model for nanofluids with volume fraction less than unity. Maxwell equation is given by

$$\frac{knf}{k} = \frac{ks + 2k + 2\phi(ks-k)}{ks + 2k - \phi(ks-k)}$$

The specific heat of the nanofluid (Cp,nf) is calculated using Xuan and Roetzel's equation.

$$(\rho Cp)nf = (1-\phi)(\rho Cp) + \phi(\rho Cp)s$$

The viscosity of the dilute nanofluid lnf can be determined using the viscosity correlation proposed by Einstein

$$\mu nf = \mu(1+2.5\phi)$$

Substance	Density(kg/m³)	Specific heat (J/kg K)	Conductivity (W/m-K)	Viscosity (kg/m.s)
Al_2O_3	4000	880	30	-
Water	998	4190	0.58	0.001003
Nanofluid	1058.04	3939.87	0.6134	0.000952

Fig 10.2: Representation of conductivity of heat mass variation

m. Results

Comparison between water and nano fluids

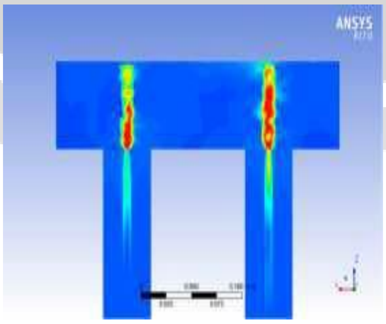

Fig 10.3: conductance of heat in water

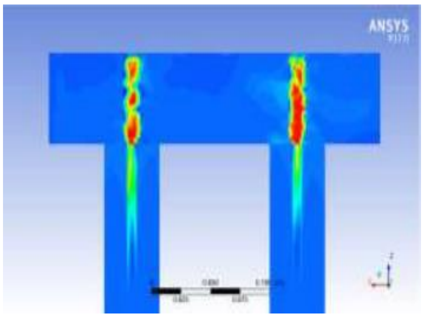

Fig 10.4: Conductance of heat mass in nano fluids

From the above figure the temperature difference of evaporator and condenser for system using nanofluid is lesser than system using water as working fluid. It shows that effective thermal conductivity of heat pipe SWH increases when nanofluid (Al_2O_3+water) is used.

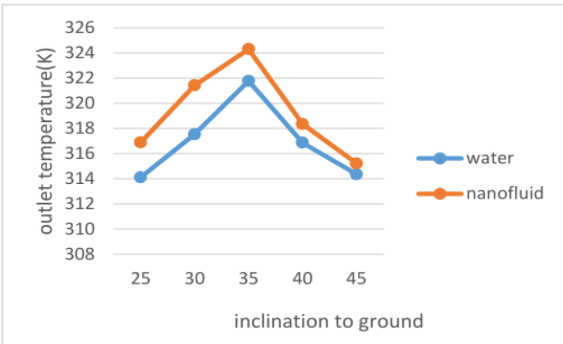

Fig 10.5: Variation of outlet temperature with inclination at 5LPH

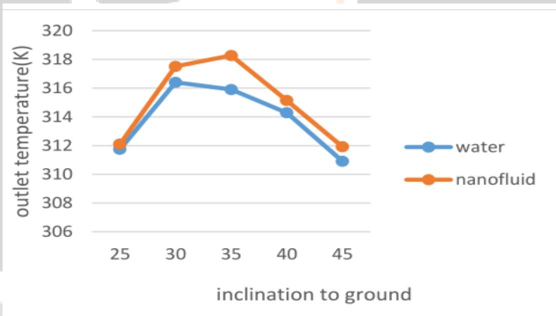

Fig 10.6: Variation of outlet temperature with inclination at 10LPH

Variation of outlet temperature with inclination at 15 LPH

From the above four graphs it is clear that the intensity of the solar radiation remained same for the analysis. Hence the temperature varies with mass flow rate and inclination. The solar radiations are calculated by solar calculator in FLUENT and applied as boundary condition for evacuated tube.

11. FUTURE WORK

- One of the drawbacks of ETSC is that the collector tubes are very fragile and easy to be damaged. To overcome this drawback, research can be carried out on improving the structure of evacuated collector to make their body harder. For example, nanotechnology can be used to build a harder and powerful evacuated collector.
- Evacuated tubes are made of annealed glass which is much more fragile than tempered glass and the material mostly used is borosilicate glass. Experiments can be done on materials of glasses used in evacuated collector to have better efficiency.

- Grooved tubes which have spirally running grooves in inner surface can be used instead of usual tubes inside the collector to improve the efficiency. The heat transfer coefficient of grooved tube is said to be 2–3 times higher than plan tube with same specification.
- The effectiveness of heat transfer is directly related to the working fluids of the collector to absorb the heat energy from the absorber plate. From the literature, ETSCs have been commercially available for more than 20 years and water is being used as the working fluid which has several hundred times low thermal conductivity than working fluids with metal or metal oxide. Based on comprehensive studies, it has been also realized that very few studies were conducted on ETSCs using nanofluids. As the evacuated collectors have better performance in producing high temperature due to minimal convection and radiation losses, using nanofluids in ETSC is expected to raise the efficiency significantly.
- Solar collectors are basically of two types namely stationary and tracking, ETSCs are of stationary type.
  For stationary type solar collectors sun tracker can be used to track the maximum sunlight throughout the day. Though the cylindrical shape of the ETSCs helps to track the sun passively throughout the whole day but it is not able to absorb the maximum sunlight as the solar panel is positioned with a fixed angle. Solar tracker is able to orient the collector along the direction of the sunlight and ensures the absorption of maximum sunlight throughout the day by adjusting its orientation according to the sun.

12. CONCLUSION

Our models predict that for low- to mid-temperature applications at incident fluxes less than 100 suns, receivers comprising blackbody absorbers and aerogels are at least as efficient as current state-of-the-art selective surface evacuated receivers. These aerogel-based receivers could supplant traditional evacuated tube receivers, such as those used for high-efficiency domestic hot water and solar thermal troughs; reliability and cost will be the deciding factors. Because they do not need to be evacuated, aerogel-based receivers could bring the high efficiency normally associated with evacuated tube receivers to additional form- factor receivers such as flat panels.

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