PERFORMANCE COMPARISON OF EVACUATED TUBE SOLAR COLLECTOR'S: A REVIEW

Jayesh Ashok Mahajan[1], Dr. Adwait Manoharrao Vaidy[2]

[1]*Shri Sant Gadge Baba College of Engineering Bhusawal, India*

Abstract: *Solar energy is the most abundant, environmentally favorable, and sustainable energy source for meeting the growing demand for electricity. Solar energy is collected by solar collectors, and the most efficient and convenient collector among different types of solar collectors is an evacuated tube solar collectors. This paper offers an overview of recent evacuated tube solar collectors studies and revealed that this collector has great potential in the commercial, residential, and agricultural sectors. Due to their higher efficiency and high outlet temperature, Evacuated tube solar collectors have been used for water heaters, solar cookers, a drying agricultural products, and for many other purposes. Typical applications of the three types of evacuated tube solar collectors are provided to demonstrate the degree of their applicability to the reader. An evacuated tube collector was found to have greater performance than the other collector. Also, an evacuated tube collector is very good for use at higher operating temperatures.*

Keywords: **Solar energy, Evacuated tube collectors, Applications, Efficiency, Operating temperature, Operating temperature, Comparison, Heat pipe, Phase change liquid, Thermosyphon, Temperature range.**

Contents

1. INTRODUCTION

Now a day's very high energy demand for industrial, agriculture, and domestic sectors for this reason high requirement of fossil for energy generation, but due to environmental pollution and global warming, it is very essential to find out alternative sources of energy to complete the today's energy demand for various sectors. The researchers and scientists focus on researching alternative energy sources that are gifted to us from the environment. Sun and wind are among the energy sources capable of being properly limitless and available in ample amounts and around the world at no cost. The different types of collectors are used to collect solar energy from the sun in the form of radiation and transfer to the working fluid. The solar collector performance is eminently dependent on its optical and geometrical properties, orientation, and microclimatic condition, geographical position and the how long period use. [1]. Various systems have been

developed for solar energy utilization that collect solar energy and convert into a required alternative form of energy, such as for drying for agricultural use, electricity generation, and a hot water system. This system's very important component is solar collectors which absorb solar radiation from the sun and convert it into the required form of energy such as for water heater system water heated by solar energy. Hot water is used for agriculture, domestic and industrial purposes. [2] In this paper evacuated tube solar collector is considered. The output energy of the sun is 3.8×10^{20} MW it is equal to the 63 MW/M^2 of the sun surface, if only a small amount 1.7×10^{14} kW, of total sun radiation emitted is avoidance by the earth then this small amount of radiation falling on earth for 30 minutes it is equal to the one-year energy demand of the world. Energy is known as the prime agent in producing electricity Power, and a big factor in economic growth. Energy 's importance to economic development is Universally and historically recognized evidence check the existence of a strong relationship between the availability of energy and economic activity. As if in the early 70s, after the oil crisis, energy costs were a concern, in the past two decades, environmental risks and the reality Degradation became more noticeable. The Riding It is because of a combination of environmental problems
of several factors since the human impact on the environment Activities have evolved exponentially. This is because of the increase in the world population, energy consumption, and industrial operations. Achieving sustainability issues that humanity faces today needs capacity in the long term Sustainable development initiatives. In this respect, it is removable energy resources appear to be amongst the most productive and efficient solutions. A few years ago most analyzes of the climate and Legal instruments of regulation based on traditional Contaminants such as sulfur dioxide (SO_2) and nitrogen oxides Particulate matter (NOx), and carbon monoxide (C_O). Already the environmental issue has however spread to the Management of dangerous air contaminants, usually toxic Material substances dangerous except in the case of small doses, and other globally significant doses Pollutants for example carbon dioxide (CO_2).

Acid rain is a form of pollution abatement where SO_2 and NOx created by fossil fuel combustion is carried into the atmosphere over vast distances And accumulated over the earth by precipitation, causing damage for habitats that are highly vulnerable to excessive acidity. So it's clear that the solution to the problem The deposition of acid rain requires proper monitoring of Pollutants of SO_2 and NOx. Both of these pollutants cause Acid drainage problems regionally and trans boundary. Any of these contaminants cause Acid drainage problems regionally and transboundary. Other substances such as this are also the subject of attention recently Chlorides, ozone, as volatile organic compounds (VOCs), And trace metals which can be included in a diverse collection of Material chemical transformations end in an acid Precipitation and additional regional air formation Contaminants.

Ozone layer depletion The ozone present in the stratosphere, at altitudes Plays a natural balance between 12 and 25 km The position of the earth, by the absorption of Radiation ultraviolet (UV) (240–320 nm), and absorption A global environmental concern is the degradation of the stratospheric ozone layer caused by CFC, halon (chlorinated and chlorinated) pollution. Natural brominated compounds) and the NOx. Depleting ozone Can cause higher rates of damaging UV radiation Rising to the ground, causing elevated skin cancer rates And human eye injury, and it is harmful to many Species Biological for radiation under infrared. It should be remembered that this relates to electricity Activities are only partially responsible (directly or indirectly); For those pollutants that cause stratospheric ozone Deployment. The most important role in depleting ozone is The CFCs, used mainly in air conditioning and Refrigerating systems as coolants and NOx emissions Which Fossil Fuel and Biomass Produces Combustion, Carbon Denitrification, and Nitrogen processes Feeding stuffs.

Global climate change generally the term greenhouse effect was used for The function of the entire atmosphere (principally water vapor and clouds) keeping the terrestrial surface warm. Already It has however been increasingly linked to the contribution of CO_2 which is estimated that contributes around 50 percent to the anthropogenic greenhouse effect. Additionally, several other gasses such as CH4, CFCs, Halons, N2O, ozone, or peroxyacetylnitrate (also known as Industrial and domestic greenhouse gases) Activities may also contribute to that effect, leading to an increase in Temperature of the world. Rising concentrations in the atmosphere of greenhouse gasses, heat increases Caught (or reduced heat from the Earth Surface), thereby elevating the surface temperature Earth. The surface of the earth according to Colombo The last time temperature rose by about 0.68 ^{0}C the century and consequently the sea level was expected to be Up by perhaps 20 cm. Such adjustments can go a long way Variety of impacts on human activities worldwide.

2. Evacuated tube solar collector

Solar collectors are graded as stationary and traceable in two groups Fig 1. For example, different collector configurations can support a wide temperature range, 20 to 80 °C is the operating temperature range of a flat plate collector (FPC), and 50–200 ° C is a solar collector for an evacuated tube. Compared to normal FPC with ETSC has considerably lower cost and heat loss.

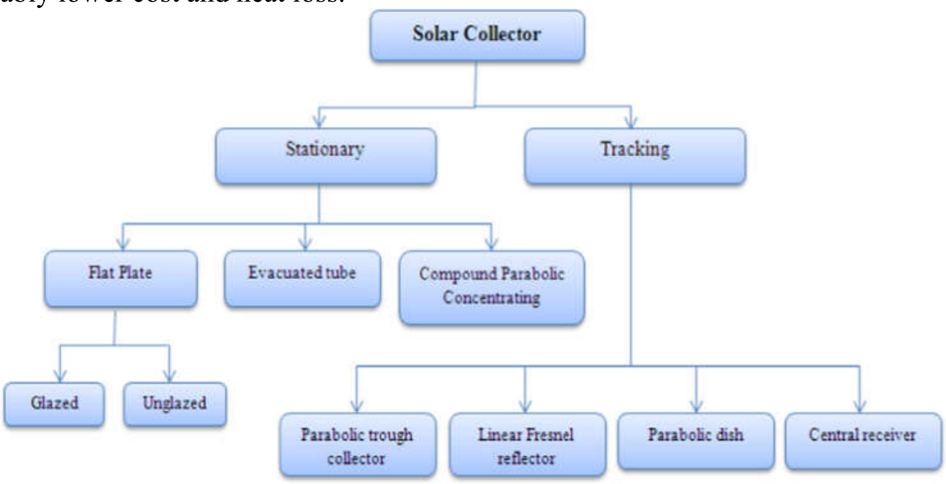

Figure1. Types of solar collectors [4]

On the other side, due to the presence of a vacuum in annular space between the two concentric glass tubes, an ETSC reduces all of these issues, which prevents sun-tracking due to its tube-shaped nature. Conventional FPCs are generally designed for warm and bright weather conditions. On a cold, windy, and cloudy day, their output decreases, and they are greatly influenced and affected by the weather as moisture and condensation cause early degradation of internal materials, which could cause early system harm. In comparison, ETSC has excellent thermal efficiency; the system is compact and easy.

The collector of Evacuated or Vacuum tubes consists of several rows of parallel transparent glass tubes connected to a header pipe where the heat transfer fluid (usually 50 percent Propylene Glycol) circulates and absorbs the heat produced by tubes. The shape of those glass tubes is cylindrical. The angle of sunlight is therefore often perpendicular to the heat-absorbing tubes that allow these collectors to work well even when the sunlight is weak, such as when it is early in the morning or late in the afternoon, or when it is shaded by clouds. Evacuated tube collectors are made of one or more parallel rows of clear glass tubes supported on a frame. Depending on the manufacturer, each tube ranges in diameter from 1 "(25 mm) to 3" (75 mm) and from 5′ (1500 mm) to 8′ (2400 mm) wide. Each tube is composed of a thick glass outer tube and a thinner glass inner tube (called a twin-glass tube) or a thermos-flask tube covered with a special coating that absorbs solar energy but prevents heat loss. The tubes are made of borosilicate or lime soda glass, which is solid, resistant to high temperatures, and have a high solar irradiation transmittance.

Evacuated tube solar collector is made of evacuated glass two tubes; one outer and other is inner it coated with coating while the outer tube is transparent shows in Fig.2 Sunray passes through outer tube and it absorbed through coating by inner tube. Minimum reflection quality of evacuated tube; the inner tube is heated by absorbing the sun rays due to the vacuum between inner and outer tube no heat losses occurs. Therefore the evacuated tube solar collector is more efficient. [4]

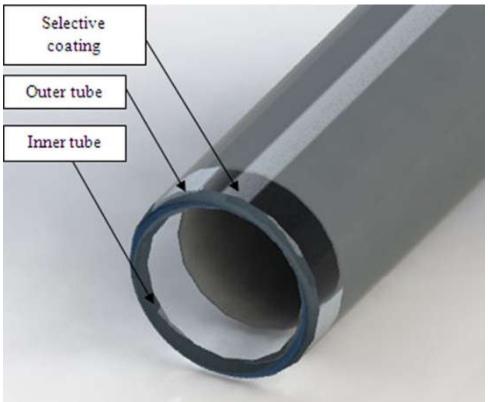

Figure 2 Evacuated tube [4]

2.1 Water-in glass evacuated tube solar collector

Evacuated tube solar collectors are used pump or thermosyphon circulation of water between the storage tank and solar absorber array. Water-in glass evacuated tube solar collector this type of solar collector evacuated tube is directly inserted into the low-pressure water tank shows in Fig. 3 this type of solar collector is widely used for water heating purposes.[5] Evacuated tubes consume solar energy and transform it for use in heating water. The solar thermal collectors use several types of evacuated tubes. Sunflower solar collectors use the "twin-glass tube" most commonly used. This type of tube is selected for reliability, performance, and cost-efficiency. Ach evacuated tube consists of two borosilicate glass tubes consisting of extremely solid glass. The outer tube is translucent and allows for limited reflection of the sunlight. The inner tube is coated with a coating of aluminum nitride (Al-N / Al). This selective surface is perfect for absorbing solar radiation with limited loss of reflection. The air contained in the space between the two layers of glass is pumped out during the fabrication process, while the top of the tubes is exposed to high temperatures. This fuses the two tubes into one single evacuated tube. This "evacuation" of the gasses creates a vacuum which is the most important factor in achieving the evacuated tubes' high efficiency. The vacuum removes a physical link between the tube's two glass layers which means that there is nothing to transfer thermal energy, so that heat can not escape! This is necessary because we do not want to lose it until the evacuated tube absorbs the radiation from the sun and converts it to heat!! To accomplish this the vacuum allows. To accomplish this the vacuum allows. The insulation properties are so strong that although the tube inside might be 150 ºC/304 ºF, the outer tube stays within a few degrees of the temperature of the ambient air. This means that even in cold weather when flat plate collectors perform poorly under these conditions due to heat loss, evacuated tube water heaters will perform well.

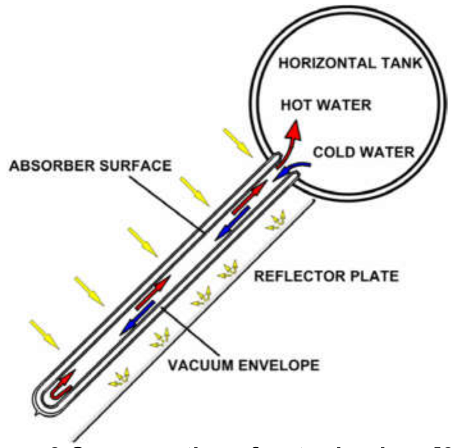

Figure 3 Cross-section of water-in-glass [6]

It consists of 15 to 40 connected to the horizontal tank, heat transfer of this collector is purely by natural circulation of water between tubes water heated by solar radiation absorbed by evacuated tube. High input heat results in higher variation in density between hot and cold stream in the tube, due to this higher pressure head. Water viscosity is smaller at the higher temperature, the axial and radial components of gravitational acceleration is determines by an inclination of a collector. The primary natural circulation drives by an axial component of gravity and secondary circulation around the circumference of the tube id determine by the radial component. [6] If 100% ethylchlorosilane and hexamethyldisilazane solutions use the static contact values increases. The antireflective films have displays long term stability for a humid environment, low and high temperatures. [7] It increases the difference between ambient temperature and working fluid leads to increases the exergy efficiency and decrease energy efficiency. [8] Exergy efficiency is highly dependent upon solar radiation and its intensity; it is negative by increasing the mass flow rate of the fluid. [9]

2.1.1 Efficiency & working temperature range

Different studies have been carried out to classify the overall performance of water-in-glass evacuated tube collectors and the findings show that Glass tube collector has adequate efficiency to increase water temperature about 80 oC, thus increasing efficiency up to 50%, which is rolling about 40% for regular glass tube collector. [14] An ETC can easily hit relatively high water temperature levels exceeding 100 oC during its service. Due to the large difference in ambient temperature, operating the collector at these high temperatures causes substantial losses in the form of latent heat working to evaporate the water into vapor and excessive heat loss. [11]

2.2 Evacuated tube heat pipe solar collectors.

Evacuated tubes consist of two compressed glass tubes enclosed at the ends, and the inner tube is filled with a selective solar coating. A vacuum is created between the two tubes, eliminating loss of convection and providing excellent thermal insulation. The solar selective coating absorbs the solar energy when the tube is exposed to the light and transfers it to a heat pipe within the inner tube. The heat pipe contains a heat transfer fluid (typically water or ethylene glycol) which transmits heat to the manifold of the device. The liquid in the heat pipe has a small boiling point, and the liquid inside the pipe starts to vaporize as it is heated and rapidly rises to the top of the heat pipe while bringing a significant amount of energy to the manifold. When the heat is discharged to the manifold, the vapor condenses and the liquid returns to the heat pipe's bottom.

An aluminum fin, retained by a spring clip in the tube, allows heat transfer and mechanically supports the in-place heat stream. [17] Shows in Fig.4

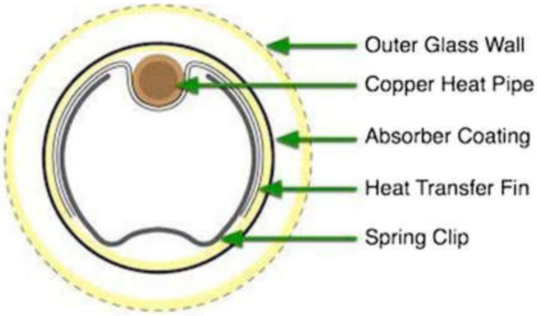

Figure 4 Evacuated tube with heat pipe [17]

The vacuum's insulation properties are so strong that while the inner tube can reach as high as 150 ° C, the outer tube is cooler to touch. This means that evacuated tube water heaters can perform well, and even in cold weather where flat plate collectors perform poorly due to heat loss can heat water to relatively high temperatures. The downside, however, is that they can be considerably more costly than regular flat plate collectors. Evacuated tube solar collectors are well suited for commercial and industrial applications of hot water heating and can be an effective alternative to flat plate collectors for domestic space heating, particularly in areas where it is often cloudy. Evacuated tube collectors are more modern and effective overall compared to traditional flat plate collectors because they can draw heat out of the air on a hot, rainy, overcast day and do not need direct sunlight to work. The overall efficiency in all areas is higher due to the vacuum within the glass tube, and there is better output even when the sun is not at an ideal angle.

The table1 shows the performance of evacuated with heat pipe collectors on different heat pipe fluid various operating conditions found out by the researchers.

Table 1 Previous research work on evacuated tube heat pipe solar collectors

Author	Journal	Type of investigation	Working fluid	Types of ETSC	Objective	Results
[1]	Journal Of Renewable And Sustainable Energy	Theoretical & Experimental	Water	Evacuated tube with heat pipe collector	Evacuated tube with heat pipe collector model	The collector efficiency has been shown to decrease as the ratio of inlet temperature to incident radiation increases. To obtain more heat and higher efficiency, it is recommended that the temperature of the inlet water be kept as close to the ambient temperature as possible.
[2]	Elsevier	Experimental	Water	ETC	Evacuated tube solar collector with multifunctional	In this study we improved the Evacuated Solar Tube significantly Collectors (ETCs) use Carbon Nanotube (CNT) sheet coatings to increase the absorption of solar energy and Phase Change Materials (PCMs) to

					absorber layers	increase heat retention for use in solar water heaters.
[4]	Elsevier	Theoretical	Water/ Air	ETC	Progress and latest developments of evacuated tube solar collectors	The evacuated tube collector has been found to have greater efficiency than the other collector. Also, an evacuated tube collector is very good for use at higher operating temperatures. There are few problems that have been reported for installing an evacuated tube solar collector and need to be carefully addressed.
[10]	Elsevier	Experimental	Water	A collector based on heat pipes typically requires a similar collection of tubes	Experimental Investigation of the Performance of Evacuated -Tube Solar Collectors	The findings show that collectors based on heat-pipe are better than water-in-glass designs and their performance is approximately 15 to 20 per cent higher.
[15]	Journal Of Solar Energy	Experimental	Air	Evacuated tube solar air collector and manifold channel	Experimental Study of Thermal Performance of One-Ended Evacuated Tubes for Producing Hot Air	Observed the solar air collector tube evacuated in case of reflector Higher outlet temperature and temperature difference, and better thermal efficiency compared to the non-reflective case. At a flow rate of 6.70 kg / hr, the average outlet temperature and air temperature difference is found to be 97.4 0C and 74.4 ^{0}C.
[25]	(Icafee' 2014)	Experimental	Water	Copper thermosyphon with outside diameter of 22 mm and 620 mm length were investigated.	Evaluation of Convective and Radiation Heat Loss on Thermosyphon Pipe	Thermosyphon available for working fluid water with specific filling ratio of 60, 70, 80 and 90 per cent and aspect ratio 9.8. The filling ratio of 60 per cent is found to be a good result.

[26]	Indoor And Built Environment	Theoretical and Experimental	Air	ETC	Thermal analysis on charging and discharging behaviour of a phase change material-based evacuate tube solar air collector	The collector's average maximum efficiency was 17.9 per cent at a high air flow rate during simultaneous PCM charging and discharge. The average total energy flow rate was 1,01 to 1,02 times higher than the low air flow rate. Flow velocities.
[27]	Advances In Natural And Applied Sciences	Experimental	Water	ETC with wickless heat pipe	Experimental investigation on theperformance of evacuated tube solarcollector with wickless heat pipe under Iraqclimatic conditions	The findings show that the optimum filling ratio and angles of inclination are 70 percent, and it is suggested to introduce 45 degrees respectively as compared to other values during the course of analysis. Therefore, the evacuated solar tube collector with filling ratio and inclination angles in Najaf citywickless heat pipe is 70 per cent and 45 degrees respectively to achieve optimum thermal efficiency.
[28]	ASME	Theoretical	Water	ETC with With Phase Change Materials And Silicone Oil	Evacuated Tube Solar Collectors Integrated With Phase Change Materials And Silicone Oil	Improvement of 26% in normal operation and 66% in stagnation mode compared to standard solar water heaters lacking phase-changing materials and silicone oil. The advantage of this method includes improved functionality by delayed heat release, thus providing hot water during high de-mand hours or when such solar intensity is insufficient in a cloudy day and night time.
[29]	Ijariie	heoretical	Water	Literature review	A Survey On Effect Of Heat Transfer enhancement On	The Evacuated tube collector comprises several rows of parallel transparent glass tubes attached to a header. Pipe used in the blackened heat absorbing

					Solar Water Heater By Evacuated Tube Heat Pipe	plate that we used in the previous flat plate collector. Various types of glass heat pipe materials were used with different profile.
[30]	Elsevier	Experimental	Water/ Space heating	ETSC	Experimental investigation and thermodynamic performance analysis of a solar dryer using an evacuated-tube air collector	-\Appropriate for solar drying applications without preheating the exhaust air. Proposed model show every good correlation coefficient for all the products (apple, carrot sand apricots) used for testing purpose. Can be the greater quantities of drying items in both the manufacturing and agricultural sectors.
[31]	Elsevier	Theoretical and Experimental	Water	Two layered glass U-tube evacuated tube	Investigating thermal performance of a filled type and the copper fin evacuated tube with aUtube.	Finned type evacuated tube with Utube reaches satisfactory thermal performance. The thermal efficiency for the filled style evacuated tube is 12 per cent higher given that the heat transmission of the device is 100.
[32]	Iciiime 2017	Experimental	Water	water-in-glass evacuated tube	Effect of Inclination Angle on Temperature Characteristics of Water in-Glass Evacuated Tubes	The experiment shows the output differs with respect to inclination angle. The data obtained during the experiment indicate the highest water temperature values for smaller angles of inclination (15 degrees) at the earlier stages of the test
[33]	Elsevier	Theoretical	Water	ETC with heat pipe	Design of Evacuated Tube Solar Collector with Heat Pipe	Heat pipe collectors output was found to be more sensitive to external conditions, such as solar radiation, ambient temperature. An important parameter for design is the length of the evaporator to condenser segment
[34]	Taylor &	Theoretical and	Water	ETC	Performance Study	Active and passive solar stills with and without

	Francis	Experimental			on Evacuated Tubular Collector Coupled Solar Stillin West Texas Clima	external insulation were tested to investigate the viability of the solar tubes. The results showed that the increase in the still with evacuated solar tubes increased its capacity for production by a factor of 2,63. It also increased the water's maximum temperature in the still basin by a minimum of 20 °C.
[35]	Taylor & Francis	Theoretical and Experimental	Water	ETC	A study of the effects of water capacity on the thermal performance of water-in-glass evacuated tube solar collectors applied to space heating	This paper studies the thermal performance for space heating of water-in-glass evacuated tube collectors, and focuses mainly on the effects of water capacity. A dynamic model is developed and experiments are conducted with the water-in-glass evacuated tube collector applied to space heating systems.

Comments: After review the above literatures found that many researchers studied on improve the performance of evacuated tube solar collector by using the different method like increasing the length of thermosyphon, specific ratio of filling with inclination angle, adding the thermal fluid in the ETC for heat storage propose, by providing groove and coating inside the heat pipe to achieve the specific result.

2.2.1 Efficiency & working temperature range.

Heat pipe Evacuated solar collector tube output was found to be 60.7 % and system output was found to be 50.3 %. Solar energy collectors act as heat exchangers which convert the energy from solar radiation into the transport medium's internal energy. Evacuated tube solar collectors are popular and can reach higher temperatures than 50-130 °C flat plate collectors. The key issue with evacuated tube solar collector is heat extraction from the long thin absorber, different methods are used to extract heat from the evacuated tubes. [18]

2.3 U-type evacuated tube solar collector

Fig.5 displays an evacuated U-tube solar collector This consists of an external glass tube, an internal glass tube, a copper or aluminum fine, and a copper tube made in U shape. The incident solar radiation is passed to the inner glass tube and is absorbed by the fin on the outer surface of the outer glass tube. The energy gathered from the fine is passed to the U-tub through conduction.[12]

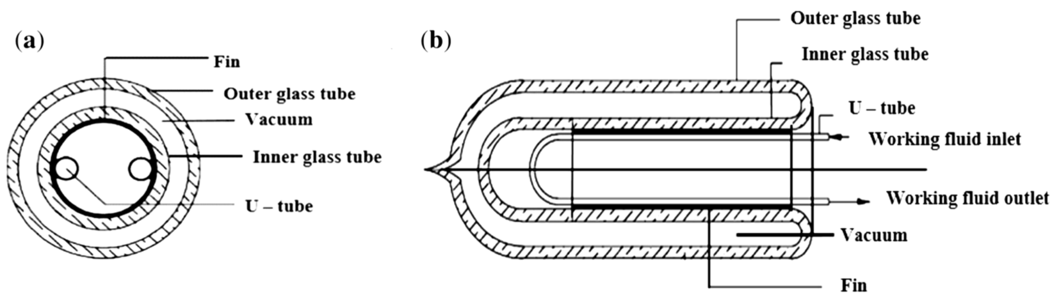

Figure 5 Evacuated U-tube solar collector (a) Cross section and (b) longitudinal section. [12]

Water evacuated in glass and U tubing in the collectors. Results showed that the energy density of U pipe evacuated collectors is 25–35 % higher than that of water in the glass. Therefore, they concluded that the flow rate and the thermal mass of the fluid affect the energy storage and also the pump operations. It is noted that energy collection efficiency will be lowered for a higher flow rate. According to him, ETC is solid and durable. If any tube is broken, this is simply replaced and is considered a cheaper alternative. [13]

2.3.1 Efficiency & working temperature range.

The use of solar energy, especially solar thermal energy, has been an important component of renewable energy usage. Medium temperature is inevitably needed for solar energy applications in air conditioning, cooling, building heating, desalination of seawater, thermal power generation, etc. Static low-concentration evacuated solar collector tube (LCET) for medium-temperature applications optical average output can hit 76.9% and system efficiency is 62%; the mean temperature range of 80 and 1400C. [15]

3. Mathematical model.

Nomenclatur

ETSC	Evacuated Tube Solar Collector.
C_0	constant
C_1	constant (Wm^{-2} k^{-1})
C_2	constant (Wm^{-2} k^{-1})
τ	transmittance α absorptance
Q	heat rate (W)
Q_L	thermal loss (W)
Q_u	net heat energy absorbed by working fluid (W)
S	solar energy absorbed by selective absorbing coating (W)
D	outer diameter of the absorber tube (m)
L	the length of the absorber tube (m)
A_c	surface area of the collector (m_2)
G	solar irradiation (W/m_2)
C_p	specific heat at constant pressure (j/kg ^0C)
$\dot{m}$	mass flow rate(kg/s)
T_{out}	fluid outlet temperature (^0C)
T_{in}	fluid inlet temperature (^0C)
T_m	mean temperature of heat transfer fluid (^0C)
T_a	ambient temperature (^0C)
F_R	collector heat removal factor

U_l	overall loss coefficient ($Wm^{-2} k^{-1}$)
U_t	the edge loss coefficient of the header tube ($Wm^{-2} k^{-1}$)
U_e	the loss coefficient from the absorber tube to the ambient ($Wm^{-2} k^{-1}$)
K_θ	incident angle modifier
a	incident angle modifier constant
ϕ	nanoparticles volume fraction (%)
η	collector efficiency

There are two different methods for calculating solar thermal collector efficiency: a steady-state test method and a quasi-dynamic test method. In the steady-state test process, the boundary conditions for solar irradiation, ambient temperature, and collector inlet temperature are kept constant, and for quasi-dynamic testing, the boundary conditions are free to vary. Solar energy is the source of heat on the solar collectors in both techniques; therefore, irradiation is the input power that the collector collects and receives, and then passes to the working fluid. Thermal losses occur when an ETSC is involved in the heat transfer process. Transfer of heat may take place through conduction, convection, and radiation. The heat transfer processes need to be included to perform heat balance. Thermal loss may be expressed as Q_L

$$Q_L = S - Q_U \tag{1}$$

The valuable heat that a solar collector provides is the difference between the energy that the working fluid receives and the heat lost from the surface to the surroundings.

$$Q_U = S - Q_L \tag{2}$$

Under stable conditions solar collector thermal efficiency can be determined as follows:

$$Q_U/A_C = F_R(\tau\alpha)G - F_R U_L(T_m - T_a) \tag{3}$$

From Eq. (3), It is observed that the thermal performance of the solar collector depends on the strength of the sunlight that strikes the collector surface, the temperature of the surrounding atmosphere and the absorbing layer, and the optical and thermal performance of the collector, respectively, expressed by the values of (τα) and UL. The transmittance of the glass cover and absorption (α) of the absorber plate depends on the collector's incidence angle and approximately 0.836 is the sum of the transmittance and absorption (τα) according to literature [4].

$$Q_U = \dot{m}C_P(T_{out} - T_{in}) \tag{4}$$

Where Cp is the basic heat of water; defined heat can be measured using Eq in the case of nanofluids. (5)

$$C_{p,nf} = \phi c_{p,np} + (1 - \phi)c_{p,bf} \tag{5}$$

Where nf, np and bf subscripts are for nanofluid, nanoparticles, and base fluid, respectively. An ETSC's thermal efficiency can be calculated using both Eqs. (7) to (8) [4].

Efficiency; $\eta = Q_U/A_C\ G_n$ (6)

Therefore; $\eta = \dot{m}C_P(T_{out} - T_{in})/A_C G$ (7)

Eq. (7) provides the efficiency of the evacuated collector with the known value of the fluid mass flow rate and the fluid inlet and outlet temperature calculated. Another way of getting efficiency is by calculating the net output power by considering the heat losses shown in Eq. (8).

$$\eta = F_R(\tau\alpha)G - F_R U_L(T_m - T_a)/G \tag{8}$$

The temperature of the absorber plate and U_L is not a constant. The heat removal factor of the collector is a function of the flow rate. Fluid temperature and absorber temperature are not the same the difference between them is 0 to 1. Collector efficiency depends on the coefficient of heat loss (U_L) and the design of the collector's absorber plate. Therefore, the approach to obtain ($F_R U_L$) is

$$F_R U_L = C_1 + C_2(T_m - T_a) \tag{9}$$

By combining Eqs. (8) and (9), [3]

$$\eta = F_R(\tau\alpha) - C_1(T_m - T_a)/G - C_2(T_m - T_a)^2/G \tag{10}$$

But the Eq. (10) the measurement of efficiency is only true if the sun reaches the collector perpendicularly because the sun is not always perpendicular to the collector. Light is perpendicular to the collector only at midday but light hits the collector with a different angle in the morning and afternoon. An incidence angle modifier (IAM) is the solution for obtaining the output for various incident angles that can be defined in the following equation:

$$K_\theta = 1 - \tan\left(\frac{\theta}{2}\right)^2, \theta = \frac{\pi}{3} \tag{11}$$

A variation of the angle of incidence is simply the multiplier of the angle of incidence for beam radiation ($K_{\theta b}$) and the angle of incidence for diffuse ($K_{\theta d}$).

Incidence angle modifier; $K_\theta = K_{\theta b} + K_{\theta d}$ (12)

The collector efficiency can be modified with the modifier of the incidence angle, expressed in Eq.(13) [6]

$$\eta = F_R(\tau\alpha)K_\theta - C_1(T_m - T_a)/G - C_2(T_m - T_a)^2/G \tag{13}$$

By combining Eqs. (12) and (13)

$$\eta = F_R(\tau\alpha)K_{\theta b} + F_R(\tau\alpha)K_{\theta d} - C_1(T_m - T_a)/G - C_2(T_m - T_a)^2/G \tag{14}$$

3.1 Applications

3.1.1 Agriculture Application

a) Drying by using Evacuated tube:-

An alternative and widely used approach is agricultural products such as vegetables and fruits with zero energy costs in hygienic, safe and regular conditions, solar drying technology. Solar dryer technology is comfortable, environmentally friendly and effective to limited amounts of food processing industries or for agricultural purposes, Produce hygienic and high-quality food products as this technology needs less space, saves time, energy and labor costs and also increases the quality of the goods. It is indirect air heating systems that circulate water through the pipeline to the water-to-air exchanger through the evacuated tubular solar collector. Outdoor drying was more effective in shortening the half drying time for all drying materials than indoor drying. Solar drying system and oyster mushroom drying outdoors showed the same half drying time. [19] Solar Dried Agricultural & Environmental Science Journal, the commodity meets the exporting requirements, and farmers should do so. Grant them a good income. Such solar dryers will play a major role in improving the economic development of India's hot and dry climate. [20]

b) Boiler for Turmeric cooking by using Evacuated tube solar collector:-

India is one of the leading production countries for raw turmeric and other turmeric-related sub-products. In India, 76 % of the world's turmeric output lies. Traditional methods that involve cooking and drying are common practices among turmeric growers for turmeric cooking. The basic concept is the boiler, which is used to cook turmeric in a pressure vessel after which hot air is used. [21] Evacuated solar tube with heat pipe can also use for turmeric cooking because it easily achieves 200 ^{0}C temperature.

c) Hot water for dairy operation:-

Solar water heating may provide hot water to clean the pen or equipment or to preheat water that goes into a traditional water heater. Water heating can account for as much as 25 % of the energy costs of a typical family and as much as 40% of the energy used in a typical dairy plant. Those costs could be halved by a correctly designed solar water heating system. [22]

d) Hot air for farms space heating:-

Modern pig and poultry farms are raising animals in enclosed structures; temperature and air quality must be carefully regulated to optimize animal health and growth. These facilities need to replace the indoor air regularly to remove moisture, toxic gases odors, and dust. Heating this air requires a large amount of energy when required. [22]

3.1.2 Industrial Application

a) Hot water use for the textile industry:-

An Evacuated tube solar collector may be used for applications where high-temperature ranges such as steam in the textile industry for washing, bleaching, dyeing, laundry, boilers, etc. are needed. Despite of this the best alternative thermal technology for producing high temperatures up to 200 ° C is known, hot water use boiler and laundry, etc. [23]

b) Hot water use for the chemical industry:-

With an optimum combination of efficient efficiency, high solar fraction, low initial and operating costs, robustness and reliability, health, and environmental sustainability, the use of solar energy in a thermal non-domestic application should ideally be built, installed and operated to meet the unique energy and temperature requirements of the particular industrial context. Hot water is used for chemical boiling in the chemical industry, distilling, ancillary process, preheating of feed water to boilers, space heating of factories. [24]

c) Hot water use for food industries:-

Most solar thermal technologies currently are economically feasible when specific favorable climatic and consumption circumstances prevail. More so if the economic externalities associated with the potential for solar energy applications for those applications which are close to economic viability. Food industries hot water use for drying, pasteurizing, boiling, sterilizing, and heat treatment. [24]

3.1.2 Domestic Application

a) Air Conditioning:-

In recent researchers study Environmentally friendly and emission-free Air conditioning technologies as manufacturer Some emission is caused by electrical energy. Mehta & Rane suggested fluid-based desiccant air Conditioning device which is solar adaptable

Power, a renewable energy source, free of emissions. In summer the solar radiation is easily accessible that time also means the demand for air conditioning Higher which makes solar usage fair Air-conditioning fuel source. They are Experiment with a new way of using an ETSC Heat pipes used as a liquid desiccant regenerator solar dependent collector. They executed the Collector how much-activated steam at 100 Generate which has an efficiency of 51–60% for Range around 9h. The average thermal COP was 0.82 Realized that there is no heat loss to air and Power consumption was below 4W due to Low-pressure drop, and liquid desiccant flow rate Collector ...... collector.[23]

b) Solar Water Heater:-

Since the last decade, the world market has been For solar water heaters which are rapidly increasing the Performance of a wide number of new technologies Quality goods through various new technologies. A Solar Water Heater is an appliance used for heating water with solar energy to produce Vapor for both domestic and industrial use. Solar energy emanates endlessly from the sun As the solar radiation type on which it falls Air absorbing, and then converting to heat What one is used for heating water [3].

4. Efficiency Comparison

The table 1 shows the efficiency difference between the above three types of solar collectors.

Table.1 Efficiency Difference of the collectors

Sr. No	Types of evacuated tube solar collectors	Operating Temperature	Efficiencies	
			Collectors	Working
01	Water-in glass evacuated tube	50°C -80°C	50%	40%
02	Evacuated tube with heat pipe	50°C -130 °C	60.67%	50.3 %
03	U-type evacuated tube	80^0C -140^0C	76.9%	62%

5. Conclusions

Several of the most common three types of evacuated tube solar collectors are presented in this paper. The included three types of collectors are Water-in glass evacuated tube solar collectors, Evacuated tube heat pipe, and U-type evacuated tube solar collectors with their efficiencies and operating temperatures. Mathematical models and typical applications are defined to demonstrate the extent of their applicability to the reader; for industrial as well as agricultural applications, which include water heating, space heating, drying, etc. It was found that after analyzing the available literature the efficiencies and operating temperature of the U-type evacuated tube and evacuated tube heat pipe solar collectors are much better than water-in glass evacuated tube solar collectors.

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