Literature Review and Analysis of Improvisations in Parabolic Trough Solar Collector

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Abstract— Solar energy is a type of renewable energy source which is environmental friendly and helpful in sustaining the growing energy demand. The parabolic trough collectors are a conventional option used in various applications of medium and high temperature levels such as in water heating, heat engines, air conditioning, solar cooker, steam generation and solar drying for residential and industrial sectors have been growing exponentially. The current paper discusses about the conventionally used materials and different components for parabolic trough solar collector.Their effectiveness over the time can be improvised with the help of newly discovered alternative materials, by means of which the overall performance of PTSC (parabolic trough solar collector) can be improvised.

Keywords—**Concentrated Solar Power, Parabolic Trough Solar Collector, Reflector, Collector, Receiver**

I. INTRODUCTION

The energy crisis in the world are forcing us to focus our attention on different sources of energy which are sustainable and renewable. Solar is one of the most attractive options among all renewable energy resources especially for countries with abundant sunlight exposure. One of the upcoming technologies in solar energy field is concentrated solar power systems.

In this paper the parabolic trough solar collector type of CSP have been reviewed. CSP works on the principle of focusing the solar radiation onto a focal line of collector aperture. At this focal line is a receiver tube through which the heat transfer fluid flows. This HTF gets heated as the sunrays gets concentrated on the tube by the collector aperture [6]. The heated fluid is used for air conditioning, solar cooker, steam generation and solar drying and other domestic as well as industrial applications. Parabolic Trough Collector is a most upcoming and conventional technology in CSP, this technology includes focusing fraction of solar radiation which is not deviated by clouds, fumes or dust in the atmosphere and reaches the Earth's surface as a parallel beam and called as Direct Normal Irradiance (DNI) [12] .The components of PTSC that are investigated and reported in this paper are reflector, collector, evacuation system, insulated pipes and tank. Reflector consists of mirrors arranged in a parabolic shape that helps in reflecting the sunrays incident on the aperture. Collector consists of a copper tube aligned at the focal point of the parabola so as to absorb maximum radiation. The objective is to study materials which can give better results as compared to the conventional system and to make system cost effective. So as the investigation suggests acrylic sheets instead of glass mirror to reduce weight as well as cost and handling of system [3]. The paper also suggests evacuation for the collector as to avoid any convective losses which can occur when system is placed in environment [5]. The copper rod placed inside the evacuated tube is to be electroplated with black chrome/black nickel/black copper to increase its absorptive capacity[10]. The pipes which are connected to outlet of the collector as well as inlet pipes are insulated with glass wool. Tank from which the fluid (water) is circulated is also insulated for better results.

II. LITERATURE REVIEW:

The paper discusses about theoretical case study between the widely used materials for Parabolic Trough Solar Collector in the current period of time and the alternative options that are based on the investigation of various research papers.

A. Collectors
B. Receiver tube
C. Absorptive coating

Now let's look at these components individually,

A.Collectors

1) Silver Coated Glass Mirror: The most widely used material for collector is the Silver coated glass mirror[1]. The paper shows some of the experienced and investigated characteristics of silver coated glass mirrors. One of the type of glasses used is Low- iron Flat glass with relatively flat surface can be made by flat process and has a reflectivity of 0.896. Silver coating is applied on the back of the glass to establish its reflective trait. Silvered glass mirrors tend to degrade when they are kept in outdoor spaces as the silver undergoes corrosion. Therefore, they need to be properly protected or their reflectivity will deteriorate. As the glass mirrors are very fragile and so are inconvenient to manage in sheets that are considerably sized for mirror use [2].

Therefore, majority of the silver coated glass mirrors used in parabolic trough solar collectors are not manufactured in one piece but they consist of mirror fragments which reduce the reflective ability of the collector aperture due to the gaps[1]. Most Commonly used Silver coated glass mirrors have reflectivity of 0.93 [3]. These high quality low iron glass mirrors can be expensive [2],[4].

2) Acrylic Mirror Sheets: After investigating a certain amount of research done on reflective materials than can be used for collectors, the acrylic mirrors seemed like a sound option to be used as reflective materials for collector. Acrylic is nothing but polymethylmethacrylate (PMMA) [2].

A study was done by NREL and 3M Company on less-expensive durable solar reflectors which included different reflector materials such as acrylic, Silicone, Fluoropolymers, Polyacrylonitrile (PAN), Polycarbonate and Polyester films. Out of which Acrylic was found to be remarkable in its performance and reassuring from a cost per performance point of view [2]. Other added advantage of Acrylic Mirrors is that the weight of acrylic mirrors is half of glass mirrors, it is tested to be shatter resistant. Reflectivity for acrylic mirrors is high, 99% [4]. Weatherability is high as compared to the Glass mirrors. The material's reflectivity and transmissivity have strong influence on the optical efficiency and solar concentration ratio [2].

$$\eta_{Thermal,g} = \frac{q_{SolAbs-a} - q_{ThermalLoss,g}}{AG_s}$$

Where $Q_{solabs-a}$ is the radiation heat transferred from the collector to the receiver tube of a parabolic trough solar collector.

$Q_{solabs-g} = r_m \times \tau_g \times G_s$

$Q_{solabs-a} = Q_{solabs-g} \times \alpha_a$

As the maximum solar irradiance reaching every $1m^2$ the surface of the earth is approximately 1000W [2].

For Glass mirror of reflectivity (r_m) = 0.93

$Q_{solabs-g} = r_m \times \tau_g \times G_s = 0.93 \times 1 \times 1000 = 930W$

$Q_{solabs-a} = Q_{solabs-g} \times \alpha_a = 930 \times 1 = 930W$

For Acrylic mirror of reflectivity (r_m) = 0.99

$Q_{solabs-g} = r_m \times \tau_g \times G_s = 0.99 \times 1 \times 1000 = 990W$

$Q_{solabs-a} = Q_{solabs-g} \times \alpha_a = 990 \times 1 = 990W$

Where, G_s = Solar irradiance

τ_g = Transmissivity of glass cover

r_m = Reflectivity of Collector

α_a = Absorptivity of Receiver tube

Assumptions: Transmissivity of glass cover is assumed to be 100%, Absorptivity of Receiver tube is assumed to be 100% [2].

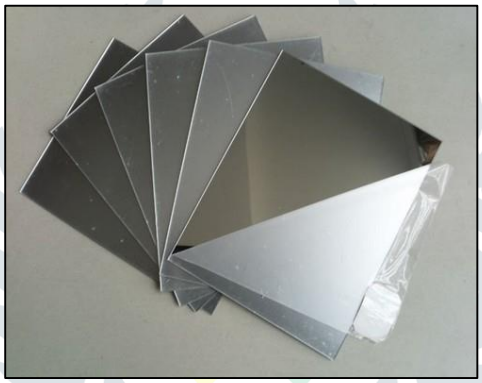


Fig 1: Acrylic mirror sheet

B. Receiver Tube:

1) *Non - Evacuated Receiver Tube:* The equation for total loss is given as:

$Q_{loss} = Q_{reflection} + Q_{radiation} + Q_{convection} + Q_{conduction}$

If a Simple metal tube is used as a receiver then none of the four components mentioned above get decreased and help in increasing the efficiency. The losses due to the movement of air over hot receiver surfaces are the convection losses. Such losses can be diminished by placing a glass cover or acrylic cover over the receiver tube in a concentric manner. The envelope results in reducing only the convection losses. Thermal losses will happen by conduction method via any medium between the hot surface of the receiver and the atmosphere which in this case is air [5].

Gases like H_2O oxidise the metal-rich absorbing layers of the film on copper selective surfaces which results into declining of the absorptivity drastically.Therefore will cause reduction in the overall efficiency in non-evacuated receivers [7].

Efficiency of receiver

$= Q_{converted} / Q_{input}$

$= Q_{input} - Q_{losses} / Q_{input}$

So, Non- Evacuated Receivers will have less receiver effieciency as there will be more losses, that is conduction and/or convection losses. In ideal scenario the non – evacuated tubes cannot be used for temperatures more than 250°C as the losses till here are not that critical [3].

2) Evacuated receiver tube:

A low iron borosilicate glass tube is to be used as an envelope for the metal receiver tube [3]. The low-iron borosilicate glass tube has a transmissivity of 0.95 [6]. The Evacuated tube will exponentially minimise the conduction and convevtion losses and give thermal output relatively higher than the non – evacuated receivers[3],[5].

Heat losses between the glass envelope and the receiver tube by conduction method are trivial for gas pressures lower than 10mpa. In ideal situations this 10mpa of vaccum should be maintained throughout its operational period. The suggested receiver tube has inner tube made of copper with selective absorber coating and the outer tube made of Clear Borosilicate. To

find out the conduction heat loss between the absorber and the envelope the total heat flux is calculated i.e. Q_T. Then all the gases in between the envelope and the absorber are exausted and now the losses are by radiative heat flux Q_R.The Thermal conduction is thus given by Q_T- Q_R[7].

The evacuated tubes are used in high temperature range of 450°C as the thermal losses in this range of temperature are critical [3].

Convection losses are calculated by: $hA(T_{receiver} - T_{ambience})$.

Where h is Convective heat transfer coefficient and A is the cross-sectional area [5].

For a complete 150m long and 828m^2 aperture of collector the thermal losses are decreased to less than 35KW for mean fluid temperature of 375°C by a evacuated receiver tube[3].

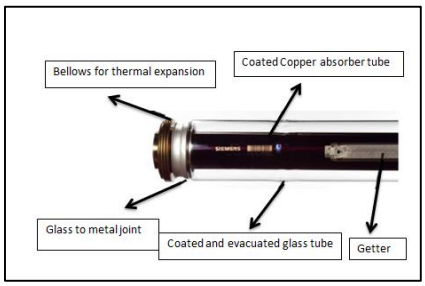
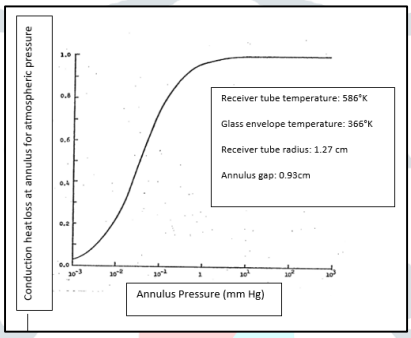


Fig: 2 Structure of a parabolic trough receiver [6]



Graph 1: Effects of Pressure on Conduct ion Heat Loss through an Annular Space [8]

C. Absorptive Coating:

1) Black Matt Coating: Black matt is one of the most widely used absorptive coating for example it was used in the Mexican Prototype. Spraying method is used for application of black matt on any metal. It was tested and proved that Black matt coating deteriorated the thermal conductivity. After experimentations it was also found that absorptivity of black matt reduced as wavelength of imposed light increased. The absorptivity of black matt is 6-7% lower than Black Chrome and Black Nickel-Chrome Coatings [9].

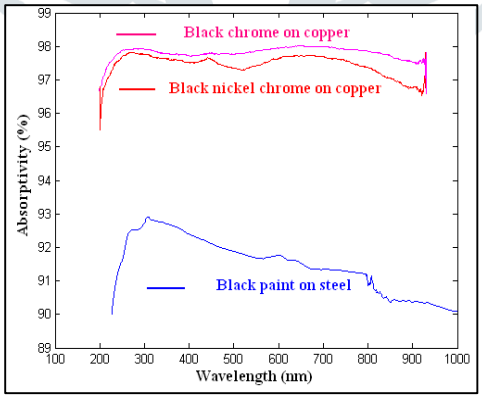


Fig 2: Optical absorptivity coefficient of studied coatings in the UV-Visible-range [9]

2) *Alternative materials as absorptive Coatings*

i. Black Copper-

Black Copper is suitable for use as a coating on copper. It can be applied on any the required metal by electroplating method. It is suitable for plating over copper as substrate.

Characteristics:-

- Absorptivity = 0.97 -0.98
- Emissivity at 100°c = 0.02
- Stability in vacuum is up to 370 °c.
- Stability in air is up to 250°c. [10]

ii. Black Chrome-

The chemical composition of black chrome is 75% chromium and 25% chromium oxide. It is Suitable for plating over copper, Stainless Steel & Bright Chromium and can be applied on these metals by electrodeposition/electroplating technique. For a smooth base and corrosion resistant properties it is plated over initial deposit of bright nickel. It also exhibits excellent resistance to moisture and used for low and medium temperature applications [9], [10], [11].

Characteristics:-

- Absorptivity = 0.97 [9], [10].
- Emissivity at 100°C = 0.09
- Stability in vacuum is up to 400 °C
- Stability in air is up to 350°C [10]

iii. Black Nickel-

It is composed of Zinc and Nickel with small amounts of carbon, nitrogen and sulphur [11].

- Absorptivity = 0.92 – 0.98
- Emissivity = 0.08 – 0.68 [9], [10], [11].
- Stability in air up to 300°C [10].

Emissivity is high therefore it needs to be coated on initial plating of bright nickel for decreasing the emissivity to 0.06 and for corrosion protection. An optimum coating can be generated with a current density of 4 mA/ cm^2 and plating period of 30 to 60 seconds. It exhibits good resistance against moisture in an atmosphere of 50% relative humidity, does not withstand high humidity environment [11].

III. Conclusion

This paper presents an overview of most widely used materials for PTSC and better alternative options for the same. Materials for collector conventionally used are silver coated glass mirrors, but with investigating of various research papers and proceedings it is concluded that use of acrylic mirror sheets is superior in terms of its reflectivity, accessibility, handling, cost etc. as compared to silver coated glass mirrors. Similarly experimentation and reports on receiver tube prove that evacuated receiver tubes give relatively higher output in comparison to non-evacuated tubes. Low iron borosilicate is the preferred material for the outer envelope as it has remarkable transmissivity. Evacuation helps to reduce convection and conduction losses and prevent atmospheric action on receiver tube. Matt black absorptive coating had been prominently used, but according to variety of experiments it has been noted that black nickel, black chrome,and blackcopper has more absorptivity and low emissivity. Therefore, use of these materials is suggested. The performance will be enhanced with the combination of alternative materials for collector, reflector and absorptive coating. This will show promising difference in the thermal efficiency of parabolic trough solar collector system and yield better results.

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