A Review of Solar Flat Plate Liquid Collector's Components

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Abstract
Main components of solar Flat plate Liquid collector are Transparent cover, Absorber Plate, Heat transport system including fluid and Insulating Material. Besides these, tilt angle and direction with respect to Sun is also very important. For best design, various materials available for all these components must be compared for their properties and configurations. The processes and Techniques which will further improve their performance must also be studied. Present study is review of various component material options and improvement techniques.

1. Introduction

Presently fossil fuels are main fuels for thermal power and there is apprehension that they will be consumed by next century. Thus the importance of Renewable Energy Sources was felt by many countries. Renewable energy resources are Solar, Wind, Sea, Geothermal and Biomass.

Solar radiation reaches the earth's surface at a maximum flux density of about 1.0kWm-2 in a wavelength band between 0.3 to 2.5 um. This flux varies from about 3 to 3 MJm-2day-1, depending on place, time, and weather. [1, pg 85]

The Solar power where sun hits atmosphere is 1017 watts, whereas the solar power on earth's surface is 1016 watts. The total world-wide power demand of all needs of civilization is 1013 watts. Therefore the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require.[2, pg 17] Solar collectors are means for harnessing solar radiation and transfer the energy in form of heat to a fluid passing in its contact. Broadly they are classified into;

A. Non concentrating or Flat Plate Type
B. Concentrating or Focusing Type

The solar collector inevitably has an absorber. In concentrating type, the area that intercepts the solar radiation is greater, sometimes hundreds of times greater than absorber area. In non-concentrating type, the area that intercepts the solar radiation is same as absorber area. This is sole basis of the above classification.

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in from the radiation at top of the atmosphere. Firstly, part of radiation is reflected back into the space, especially by clouds. Additionally radiation entering atmosphere is partly absorbed by molecules in air. Oxygen and Ozone absorb nearly all the ultraviolet radiation, and water vapor and carbon dioxide absorb some of the energy in infrared range. Lastly, part of solar radiation is scattered by droplets in clouds, by atmospheric molecules and by dust particles.

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Solar radiation that has nor been absorbed or scattered and reaches the earth directly is called "Beam Radiation". Solar radiation received after its direction has been changed by reflection and scattering by the atmosphere is called "Diffuse Radiation". The total Radiation received on any point of earth is sum of Beam and Diffuse Radiations and in general is called Insolation at the point.

The concentrating type solar collectors collect only Beam component whereas Flat Plate type solar collectors collect both Beam and Diffuse components. Therefore Flat plate type solar collector may yield result on a cloudy day also.

1.1 Solar Flat Plate Collectors

Most of the solar energy from sun comes in form of light, a short wave radiation, not all is visible. The sun radiates like a black body with surface temperature of about 57000C and maximum emission of 0.5 um. When this short wave radiation arrives at an absorbing solid or liquid body, it is absorbed as heat energy increasing the temperature of the material. Material conducts heat to surroundings or reradiates it to other materials at lower temperature. This re-radiation is a long wave radiation in wave length range of 4 to 10 um in spectrum of infra red light.

Material like Glass is transparent for solar short wave radiation and absorbent for long wave length re-radiation from absorbing material or black plate absorber. The glass absorbs infrared radiation from black plate and remits it in all directions, half of which is emitted towards black plate. The black plate absorbs this again and its temperature keeps increasing till a balance is observed between energy gain by short wave radiation and energy loss by long wave emission is reached.

Flat plate collectors are used to heat up to temperatures about 900C for space heating or water heating. They are effective partly even on cloudy day.

1.2 Classification of Solar Flat Plate Collectors

Solar flat plate collectors are classified based on type of heat transfer fluid used, as

A. Solar Flat Plate Liquid Collectors
B. Solar Flat Plate Air Collector

Liquid collectors are used for heating water and non freezing aqueous solutions and sometime for non aqueous heat transfer fluids. Air or gas heating collectors are named as air heaters.

The basic difference between these two types lies in design of passages for heat transfer fluid. Flat plate collectors have main components such as transparent cover, absorber plate, tubes or passages for heat transport fluid, insulation and a casing for these components.

1.3 Solar Flat Plate Liquid Collectors

Flat plate collectors are the most common solar collector for solar water heating system in homes and solar space heating. A typical flat plate collector is an insulated box with a glass or plastic cover (often called Glazing) and a dark colored absorber plate. [3]

Solar collector absorbs the incoming solar radiation, converting it into thermal energy at the absorbing surface, and transferring the energy to a fluid flowing through collector. Main components of solar flat plate liquid collectors are,

1.3.1 Transparent Cover (Glazing)

The material of cover should be Transparent to solar short wavelength radiation and should be opaque to long wavelength re-radiation from the heated absorber plate. Water White Glass with Low Iron content is a suitable material besides other plastic materials under research.

A portion of Heat is lost from the heated cover plate which is open to low temperature atmospheric conditions by Reflection and Convection. Convection losses can be considerably reduced by using two or three Cover Glass (with optimized spacing) instead of one cover. Reflection losses can be reduced either by Coating with anti reflective thin film of suitable substances or by soft Etching with a suitable solution on both side of the glass.

1.3.2 Black Absorber Plate

Absorber Plate of Liquid collector is typically a Metal plate of Steel, Aluminum or Copper, to which Fluid passage normally of Copper tubes are Brazen on Top or Bottom.

The surface finish of absorber plate usually is flat black paint with an appropriate (self etching type) primer. The primer coat must be thin. Alternatively Selective coatings are used to improve the effectiveness of Absorber plate. Selection coatings have high absorptivity to Short wavelength radiation (less than 2um) and Low Emissivity for Long Wavelength Radiations.

Black chrome is Low cost and High Effective option. It is a Selection coatings of Chromium sesqui oxide (Cr_2O_3) electrodeposited in thin layers on a Nickel Base. The process is Efficient but beers a cost. Black Painted sheet are cheaper and to further improve its function thin layer of coatings can be used, where cost matters.

1.3.3 Heat Transport System and Fluid

Liquid heated is generally water. Water is very effective heat transport medium but has limitations such as possibilities of freezing in tubes in cold weather particularly in cold nights. Ethylene glycol is added to check freezing but at cost of effectiveness. Another problem is of corrosion of metal by water. Lastly any leakage must be averted .

For better heat transfer the tubes are connected to common headers on top and bottom both and water enters at the botom header , moves upward through tubes, where it gets warmed by absorber plate and finally exits at the top header.

Some Nano additives improve the solar Radiation absorption capacity of fluids like water considerably. Use of Such additives also improves the efficiency of Flat Plate Collectors to a considerable extent but at a cost.

1.3.4 Insulation

Heat is is lost to the environment from the solar collector as the temperature of the absorber plate rises and collector gets warm. Rear side of the Absorber plate should be insulated in such a way that minimum heat is lost to surrounding as most of the heat lost is from the rear side, though heat is also lost from the other two sides also. Traditionally most commonly used materials are Mineral wool, Rockwool, Styrofoam etc.

Evacuated Chamber insulation is found to be most efficient but it is very costly to create and maintain a vacuum. Another very efficient Insulating material, though very cheap is thin layers of Aluminum Foil.

1.3.5 Casing

The casing is a non functional component, which supports all the other components of a flat plate collector and also acts as protection shield in adverse weather conditions. Normally it is made of sheet.

1.3.6 Direction and Tilt of Flat Plate Collector

Flat plate collectors gather Beam as well as Diffuse components of Radiation. Generally Flat Plate Collectors are fixed and do not orient towards Sun to face it always. The maximum solar radiations are received when the collector surface is facing due south. The optimum tilt is found to be Latitude angle of the location plus 0 to 15 degrees.

2. Literature Review

2.1 Collector Cover and Efficiency of Solar Collectors

Stephan Fischer and Erich Hahne [4] Explained and characterized the efficiency of solar collectors. Authors have also summarized the importance of collector cover in improving the thermal efficiency of solar collectors. The thermal efficiency of a solar collector is basically characterized by two physical phenomena: 1. The ability to convert as much of the solar radiation into useful heat as possible and 2. the ability to lose as little as possible of the converted energy to the environment. The ability to convert the solar radiation into heat is influenced by the solar transmittance τ of the collector cover, the solar absorptance α of the absorber coating and the collector efficiency factor F'. The heat losses of the collector mainly are influenced by the quality and thickness of the insulation material and the emittance ε of the used absorber coating.

The thermal efficiency of a solar collector is crucially influenced by the collector cover and its solar transmittance, because only the transmitted solar radiation is at disposal to the absorber for the photo thermal conversion of the solar radiation into heat. Thus it is very important in design of solar collector that a proper and most efficient cover and black absorber plate are selected among choice available. The properties of these materials can be modified by various techniques, which also must be taken into consideration.

Sunil K. Amrutkar, Satyshree Ghodke, Dr. K. N. Patil [5] summarized properties of materials employed in Solar Energy collectors. The important characteristics of the glazing materials are Reflectance (ρ), Absorptivity(α) and transmittance(τ). The first two should be as low as possible and the last should be as high as possible for maximizing the efficiency of collector.

Table I. below, Lists short wave solar Transmittance of Glass and other alternative material for glazing for normal incidence. The values are likely to be lower for angle of direct beam other than normal.

Fig: 1. Optical Properties of Glazing Materials

Sr. No.	Material	Solar Transmittance (τ)
1.	Low Iron Glass	0.91
2.	Polyvinyl fluoride	0.93
3.	Fluorinated ethylene propylene	0.96

Plastics posses equal or better short wave solar transmittance compared to Glass, but they are also exhibit higher long wave transmittance of the order of 0.40.

2.2 Thickness and other Optical Properties of Cover

Ramadhani Bakri, Rwaichi J.A. Minja, Karoli N. Njau [6] Explained the effect of glass thickness variation on performance of flat plate solar collectors, besides factors for consideration in selecting the glazing materials.

Glazing is top cover of solar collector. It performs three major functions in particular: to minimize convective and radiant heat loss from absorber, to transmit the incident solar radiation to the absorber plate with minimum loss, and to protect the absorber plate from outside environment. In order to attain maximum efficiency, reflection and absorption should be as low as possible, whilst transmission should be as high as possible.

After experimentation with glazing materials as low iron (extra clear) glass of thickness 3, 4, 5 and 6 mm results were studied and It were concluded that the use of 4 mm glass thick improves the performance of air solar collector by 7.6% compared to 3 , 5 , 6 mm glass thickness. However, the risk for glass breakage during construction is high when using thinner glass 4 mm compared to 5 mm and 6 mm especially, when constructing large collector with longer/wider span.

2.3 Effect of Number of Covers and Refractive Index

C. Kalidasan and T. Srinivas [7] studied effect of number of transparent covers and refractive index of covers on performance of solar water heaters in order to optimize these variables. Investigation and simulation were made with 0-3 number of covers and different refractive index values in limits of 1.1 to 1.7.

The results shows, that the efficiency of the flat plate collector increase with number of covers and decreases after an optimum number of covers. It also decreases with an increase in refractive index. The combination of optimum number (two covers) and lower refractive index (1.1) results into improved useful heat.

2.4 Effect of Cover Structure and Incidence angle Modifier

Stephan Fischer and Erich Hahne [4] compared different types of glass covers. They compared yearly energy gain obtained with unetched glass cover and glass cover etched on both side and found a gain of 3.8 % in case of etched cover. Similar gain is possible with better incidence angle modifier.

If glass cover is etched as well as it has better incidence angle modifier for beam irradiance, then a cumulative 7.6% gain is observed in yearly energy gain.

2.5 Selective Surface Coatings

Madhukeshwara N., E.S. Prakash [8] investigated on the performance characteristics of solar flat plate collector with different selective surface coatings. Selective surfaces combine a high absorptance for radiation with a low emittance for the temperature range in which surface emit radiation. A surface where most of the solar radiation is absorbed and a small amount of energy is reflected and radiated, is called good selective surface. However if the particular surface does not have good enough selectivity, it may be enhanced by adding one or more filters.

It was concluded that selection of absorber coat has influence on the performance of flat plate collectors. Maximum temperature of water is obtained for black chrome coating compared to others which were studied. Thermal efficiency is also maximum for black chrome coating.

The absorber plate surface should posses high absorptivity (α) at low wave length solar irradiation and low emmisivity (Ɛ) at high wavelength radiation from plate. Table 2 below lists some best available coatings and their respective optical properties, which have required characteristics for solar absorber plate coating.

Table: 2. Optical Properties of Selective Coating

Sr. No.	Selective Coating	Properties		
		α	Ɛ	α/Ɛ
1.	Black Chrome	**0.93**	**0.10**	**9.3**
2.	CuO on Aluminium	**0.93**	**0.11**	**8.5**
3.	Black Nickel on Polished Nickel	**0.92**	**0.11**	**8.4**

Contrary to this, emissivity (Ɛ) of non selective solar paints is in the range of 0.85 to 0.95.

2.6 Nano Fluid Based Solar Collector

Zhongyang Luo, Cheng Wang, Wei Wei, Gang Xiao, Mingjiang Ni [9] worked on improving performance of a nano fluid based solar collector based on direct absorption collection (DAC) concept.

The study indicated that nano fluid, even of low content, have good absorption of solar radiation and can improve the outlet temperatures and system efficiencies. Nano fluids improved the outlet temperature and the efficiency by 30 - 100 K and by 2 - 25 % compared to the base fluid. The photothermal efficiency of a 0.01% graphite nanofluid is 122.7% of a coating absorbing collector.

2.7 Insulation Materials

T. Beikircher, V. Berger, P. Osgyan, M. Reu and G. Streib [10] studied and found alternative insulating material for mineral wool. The compulsion for this was the fact that under dry conditions thermal conductivity of this insulating material is in between 0.035 and 0.060 w/m K. But wool can absorb humidity from atmosphere and thermal insulation deteriorates substantially.

An economical, thin and low emissive film (especially Al foil) mounted between absorber and rear casing shoes similar insulating properties as mineral wool but is not sensitive to humidity and its thermal insulation does not deteriorates in humid conditions as it does not absorb moisture from ambience. For insulation thickness between 30-50 mm, the film insulation is observed to be equal or better as compared to conventional dry mineral wool.

3. Conclusion

1. A lot of work has been done in the past in order to select right material for components of Solar Flat plate Liquid Collectors, especially Glazing and Absorber plate.
2. In selection of these materials, mostly optical and thermal properties matter to greater extent.
3. Good work has also been done in researching methods and further techniques, which improve the desired optical and thermal properties of these materials leading to better collector efficiency.

References

[1] J. Twidell, T. Weir, Renewable Energy Resource, Taylor & Francis, Third Indian reprint, 2010
[2] G. D. Rai, Non-Conventional Energy Sources, Khanna Publishers, India , 2011
[3] F. Struckmann, Analysis of a Flat-Plate Solar Collector, Project Report, MVK160, Heat and Mass Transport, Department of Energy Sciences, Faculty of Engineering, Lund University, Sweden, 2008
[4] S. Fischer, E. Hahne, The effect of Different Glass Covers on the Yearly Energy Gain of a Solar Collector, University of Stuttgart, Germany.
[5] S. K. Amrutkar, S. Ghodke, K. N. Patil, Solar Flat Plate Collector Analysis, IOSR Journal of Engineering, 2(2), 2012, 207-213
[6] R. Bakri, Rwaichi J.A. Minja, Karoli N. Njau, Effect of Glass Thickness on performance of Flat Plate Collectors for Fruit Drying, Journal of Energy, 2014, Article ID 247287, 8
[7] B. Kalidasan, T. Srinivas, Study on Effect of Number of Transparent Covers and Refractive Index on Performance of Solar Water Heater, Journal of Renewable Energy, 2014, Article ID 757618, 11
[8] Madhukeshwara. N, E. S. Prakash, An Investigation on the Performance Characteristics of Solar Flat Plate Collector with Different Selective Surface Coatings, International journal of Energy and Environment, 3(1), 2012, 99-108
[9] Z. Luo, C. Wang, W. Wei, G. Xiao, M. Ni, Performance Improvement of a Nanofluid Solar Collector Based on Direct Absorption Collection (DAC) Concepts, Elsevier - International journal of heat and mass transfer, 75, 2014, 262-271
[10] T. Beikircher,, V. Berger, P. Osgyan, M. Reu, G. Strieb, Low –e Confined air Chambers in Solar Flat Plate Collectors as an Economic new type of Rear Insulation avoiding Moisture Problem, Elsevier - Solar Energy, 105, 2014, 280- 289