Technical Features of Compound Parabolic Concentrators

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Abstract: The maximum concentration of solar radiation is achieved using a reflecting arrangement of mirrors or lenses. The optical system of advanced concentrators directs the solar radiation on to an absorber of compact area. Compound Parabolic Concentrators (CPC) is generally used for industrial application which requires medium pressure steam at around 150 degree C. Aim of this paper is to explain the terminology associated with design and fabrication of the CPC and evaluate the rise in temperature of water and its efficiency for assumed dimensions. This paper also explains the importance and specialization of CPC with respect to its performance characteristics.

1. Introduction

Compound Parabolic Concentrators (CPC) is helps to used in industrial application where medium pressure steam at around 150 degree C is required temperature level. Flat Plate Collectors are not much efficient to deliver water at temperature greater than 100 degree C. Concentrating Collectors are used to overcome this issue. The CPC belongs to the family of focusing collector, but in fact this is more alike to FPC [1]. The tracking be provided to the system. CPC has also its applications in the field of power generation, solar air conditioning, etc.

As the CPC are different than the conventional concentrating collectors, their principle of working, collector efficiency, construction need to be studied in depth knowledge. In this paper the details of the CPC has been made. Revolutionary idea behind this paper is explain one product that produces solar thermal energy, heat and electricity together in only one trough for the very first time in the world. The concentrator is of a compound - parabolic kind that concentrates light 10 times over the reflector. It is always equipped with a solar tracker to absorb more radiations [2]. The solar tracker allows maximum amount of solar concentration into the system.

2. Literature Review

Authors M. Adesten, A. Helgesson, B. Karl, in the research paper “Evaluation of CPC-Collector Designs For Stand-Alone, Roof or Wall Installation” based on numerical simulation and experimental validation of a compound parabolic concentrator (CPC) were prescribed. The solar device having an aperture area of 1.33m\(^2\), a real concentration ratio of 3.5, an acceptance half angle of 15\(^{\circ}\), and a carbon steel (or aluminum) tubular receiver with an outer diameter of 0.0603m and coated with a commercial selective surface. Experimental tests performed using water as working fluid at solar noon; the inlet temperatures used varied from 30 °C to 70 °C and the mass flow rates from 0.05 kg/s to 0.25 kg/s. A comparison between experimental results with the numerical model developed is carried out. The results of the thermal efficiency, outlet temperature, and pressure drop compared and found to be with the experimental data. The model is a reliable tool for the design and optimization of compound parabolic concentrators. This numerical model is based on the application of physical law it is possible to extrapolate its use with confidence to other fluids, mixtures, and operating conditions [3].

Authors Balbir Singh, Mahindra Singh, in the paper “Designing A Solar Thermal Cylindrical Parabolic Trough Concentrator By Simulation” explains for medium range temperature applications, focusing type collectors like Compound Parabolic Concentrator (CPC) are mostly used. Research work was carried out to improve the performance of the two dimensional compound parabolic concentrator. The three-dimensional compound parabolic concentrator is found to be more efficient than 2D CPC due to higher concentration ratio. In their work a 3D CPC was fabricated with a half acceptance angle of 4\(^{\circ}\) for a spherical absorber of radius 100 mm. UV stabilized aluminized polyester foil having high reflectivity (0.85) is pasted on the reflector for a total height of 441mm and an aperture width of 540 mm. The optical efficiency was estimated theoretically and compared with the experimental value. Experimentally determined values of optical and thermal efficiencies with theoretically predicted value. The experimental results shown that the optical efficiency obtained from the 3D CPC (0.626) was significantly higher than that of
the 2D CPC (0.570) of similar dimensions. As the optical efficiency of the 3D CPC was increased, the thermal efficiency of the collector was also increased [4].

Authors A. Castaneda Miranda, R. Castaneda Miranda, J. Meza Jimenez in the research paper “Solar Drying System For Agro-Products Dehydration” stated a regional shortages of fresh water become more prevalent, solar distillation using a single-effect basin holds promise as a way to bring low-cost, clean, and ecologically-responsible water to remote area dwellers. Compound parabolic concentrators (CPCs) is use to direct more light onto the still increasing the throughput and efficiency of these passive solar devices. A computer program has been developed which use the property of materials and the solar energy characteristics of the site to calculate the increase in output of water due to reflectors of different height [5].

Authors Essam Abdallah, Mohammed Al_Soud, Ali Akayleh and Salah Abdallah in the research paper “Cylindrical Solar Cooker With Automatic Two Axes Sun Tracking System” stated that Many people in less developed countries drink water with microbial contamination, which leads to the annual death. Some people currently boil water, all microbes that cause disease in humans does not survive at temperatures >65ºC, which solar water pasteurizers can easily produce. These pasteurizers are equal to box solar cookers, and it is having a small rectangular reflector. The objective of their work was to calculate the increase in output due to compound parabolic concentrators (CPCs) using numerical simulation. A CPC concentrates the more amount of radiation on a planar receiver. The average water temperature is independent of the solar radiation and the heat losses are nearly constant [6].

3. Characteristics

Solar Collectors

A collector is a modem to convert the energy in solar radiation into storable form. The energy of sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. Solar collectors are the main components of active solar heating systems. Solar collectors gather the sun's energy helps to transform its radiation into heat, and then transfer that heat to water, solar fluid, or air. The solar thermal energy is used in solar water heating systems, solar pool heaters, and solar space-heating systems [7].

Types of Solar Collectors

Solar collectors are having two categories: non-concentrating (thermal) and concentrating. In the non-concentrating type, the collector area is same that of absorber area. In this types the complete solar panel absorbs the light rays.

Solar Thermal Collector

A solar thermal collector basically designs to collect heat by absorbing sunlight by converting into heat energy. The term is applied to solar hot water which shows complex installations such as solar parabolic, solar trough and solar towers or simpler installations such as solar air heat.

Types of thermal collectors:
1) Flat-plate collectors
2) Evacuated-tube collectors
3) Air heaters

Residential and commercial building requires temperatures below 200°F and typically uses flat-plate collectors and those requiring temperatures higher than 200°F uses evacuated-tube collectors.

1) Flat plate collectors

Flat plate thermal system for water heating applications was deployed on flat roof flat plate collectors are developed by Hottel and Whillier in the 1950s. They are mainly consist of
(1) A dark flat-plate absorber of solar energy
(2) A transparent cover that allows solar energy to pass through but reduces heat losses,
(3) A heat-transport fluid (air, antifreeze or water) to remove heat from the absorber, and
(4) A heat insulating backing.

The absorber of system consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or copper which is a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid gets circulated through tubing to transfer heat from the absorber towards an insulated water tank. This may get directly or through a heat exchanger. The heat exchange area is more that they marginally efficient than traditional absorbers [8].

Fig.1 Flat-plate collector
2) Evacuated tube collectors

Vacuum tube collectors use heat pipes for their core in place of passing liquid directly through them. Evacuated heat pipe tubes (EHPT's) are made of multiple evacuated glass tubes each containing an absorber plate fused to a heat pipe. The heat from the hot end of the heat pipes is helps to transfer to the transfer fluid of a domestic hot water or hydraulic space heating system in a heat exchanger called a "manifold". The manifold wrapped against insulation and covered by a sheet metal or plastic case to protect them from the elements. The vacuum surrounds the outside of the tube greatly reduces convection and conduction heat loss to the outside helps to achieve more efficiency than flat-plate collectors, especially in colder conditions. This advantage is largely lost in warmer climates, except in those cases where very hot water is desirable, for example commercial process water. The high temperatures require special system design to avoid or mitigate overheating conditions.

![Fig.2 Evacuated tube collectors](image)

3) Solar Air Heat collectors

It is use for pre-heating make-up air in commercial and industrial HVAC systems. They are having two categories: Glazed and Unglazed. Glazed systems have a transparent top sheet and consist of insulated side and back panels to minimize heat loss to ambient air. The absorber plates in modern panels have an absorptive more than 93%. Air typically passes along the front or back of the absorber plate while scrubbing heat directly from it [9]. Heated air distributed directly for applications such as space heating and drying and stored for later use.

![Fig.3 Air Heater](image)

Unglazed systems also known as transpired air systems are consist of an absorber plate that air passes across or through as it scrubs heat from the absorber. These are use for pre-heating make-up air in commercial buildings.

Concentrating Collectors

The parabolic trough concentration is nearly 1/3 of the theoretical maximum for the same acceptance angle, for the same overall tolerances for the system [10]. Approaching the theoretical maximum is achieved by using more elaborate concentrators based on non imaging optics.

1) Parabolic Trough

This type of collector is use for solar power plants. A trough-shaped parabolic reflector is use to concentrate sunlight on an insulated tube or heat pipe and placed at the focal point and contains coolant which transfers heat from the collectors to the boilers in the power station.

![Fig.4 Parabolic Trough](image)

2) Parabolic Dish

Solar Parabolic dish is collector that concentrates sunlight at a single, focal point, with parabolic dishes arranged in a similar fashion to a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants.

There are two ways one is the shape of a parabola is defined such that incoming rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive and second is the light rays from the sun arriving at the Earth's surface are almost completely parallel. If dish can be aligned with its axis pointing at the sun, almost all of the incoming radiation will reflect towards the focal point of the dish and most losses are due to imperfections in the parabolic shape and imperfect reflection.
Concentrating Collectors

Concentration of Solar radiation is getting through a reflecting arrangement of mirrors and lenses. The optical system with the solar radiation on to an absorber of smaller area is surrounded by a transparent cover. Due to this losses are introduced. The combined effect of these losses like reflection or absorption losses in the mirror or lenses, and due to geometrical imperfections in the optical system shown through the introduction of a term called Optical efficiency. The more optical losses in the mirrors or lenses are confirmed by the flux incident on the absorber surface is concentrated on a smaller area. There thermal loss terms do not dominate to the same extent as in flat plate collector and collection efficiency is higher.

Due of the presence of an optical system, a concentrating collector has to follow or “track” the sun so as to get the beam radiation is directed on the absorber surface. All of the developments are line focusing cylindrical parabolic collectors, and yield temp up to 400°C.

Compound Parabolic Collector

CPC has a large acceptance angle and requires especially intermittent tracking. The benefits for the geometry of the compound parabolic collector are for solar energy collection was tremendous. A compound parabolic collector is very deep and requires a large concentrator area for given aperture. A compound parabolic collector is transitioned by about 50 percent in order to reduce its cost.

5. Design of Cylindrical Parabolic Concentrator

For designing the complete system two main vital components are designed in association with their own characteristics are as follows:

**Dimensions of Trough:**

- **i** Aperture width = 1m (considered)
- **ii** Depth = 0.25m
- **iii** Focal length = w/4 = 0.25m
- **iv** Rim Angle = 90°

Concentration Ratio For Absorber Diameter Calculation

$$C.R. = \frac{\text{Effective area}}{\text{Absorber surface area}} = \frac{(w-d_{ab})}{\Pi d_{ab}}$$

For Copper Tube = 31.53 (for 10 mm dia)
For Evacuated Tube =6.15 (for 47 mm dia)

6. Fabrication to Fulfill Design Specifications

1) Draw a parabola on with 1m aperture width & o.25m focal length
2) Cut sheet & pasting it on plywood for pattern for parabola
3) Curvature length measured,+ 5 cm is added for welding 6mm circular bars are cut to length in 12 numbers.
4) Pattern is formed and the circular bars are bending to match the shape of pattern.
5) Two angles of 25m by 1.55m length the bars are so held that exact shape of parabola is formed for pattern fixation.
6) The length and curve width is fixed and 20 gauge steel sheet is cut and fix as support plate for concentrating film and pasting of film is done on sheet.
7) Supporting steel structure for concentrator is prepared at upper side it is equipped with bearing.
8) For absorption purpose we take two type of tube as follows:

1) Copper tube
It is simplest form of tube made which is made up of copper with 10 mm diameter as per calculation of concentration ratio and coated with dull black color so maximum amount of solar energy can be absorbed.

2) Evacuated tube
Evacuated tubes absorb solar energy radiations and helps to convert it into heat for use in water heating. There are various types of evacuated tubes used in solar thermal collectors.

Evacuated tubes are comprised of two glass tubes made from extremely strong borosilicate glass. The outer tube is transparent and allows sunlight to pass through with minimal reflection and the inner tube is coated with an nickel coating.

9) The cylindrical tank is made which is suitable design for high pressure air.
10) Pipe line is designed to couple to fluid flowing path. After coupling, leakages have to check.

6. Conclusions

- Compound parabolic concentrator is easy in construction and maintenance.
- Thermo siphon process plays most important role in the complete system.
- With the help of solar tracking system we are able to concentrate maximum amount of solar energy.

By using evacuated tube in both CPC 20% greater efficiency can be achieve than cylindrical parabolic concentrator

- Compound Parabolic concentrator is depends on atmospheric conditions.

References