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A Review on Parabolic Trough Collector for Solar Thermal Applications

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Abstract- Parabolic Trough Collectors (PTCs) are one of the most commonly used Concentrated Solar Power (CSP) technologies for capturing solar energy for thermal uses. These systems use a parabolic-shaped mirror to focus sunlight onto a receiver tube that runs along the focal line of the collector. The solar energy is then turned into heat, which can be used for making electricity, heating industries, producing fresh water, and heating water. Because of their good efficiency, ability to work on a large scale, and clean operation, parabolic trough collectors are getting a lot of attention in renewable energy research. This review paper looks at the design, how they work, parts they have, their thermal performance, applications, strengths, weaknesses, and recent improvements in PTC technology. The paper also highlights the need to enhance optical efficiency, the heat transfer fluids, and thermal storage systems to improve collector performance and help in developing sustainable energy.

Keyword: Parabolic Trough Collector, Solar Energy, Concentrated Solar Power, Thermal Efficiency, Renewable Energy.

I. INTRODUCTION

Solar energy is one of the most available and sustainable energy sources on Earth.

With the growing need for clean energy and the decreasing availability of fossil fuels, there has been a faster development of renewable energy technologies. Among various solar thermal systems, Parabolic Trough Collectors (PTCs) are one of the most advanced and commercial technologies for using solar energy at medium and high temperatures.
A parabolic trough collector has a parabolic mirror that focuses sunlight onto a tube that carries heat transfer fluid (HTF). The fluid absorbs the concentrated heat and moves it for use in thermal applications. Since the collector follows the sun, it collects as much sunlight as possible throughout the day. PTCs are used in: Solar power plants, industrial heating, water desalination, solar refrigeration, and domestic water heating.

The ability of PTCs to reach temperatures between 150 and 400 degrees makes them very efficient for use in industrial and commercial settings.

II. PROBLEM STATEMENT

Traditional energy systems rely heavily on fossil fuels, resulting in: pollution, greenhouse gas emissions, rising fuel costs, and resource scarcity. Flat plate collectors have trouble working efficiently at higher temperatures, making them not suitable for many industrial processes. So, there is a need for a more efficient solar thermal system to: increase energy concentration, improve thermal efficiency, lower carbon emissions, and support sustainability. Parabolic trough collectors help with these issues because they effectively concentrate solar radiation and produce higher temperatures with better efficiency.

III. WORKING METHODOLOGY

The parabolic trough collector system has several important parts, including a parabolic mirror, a receiver tube, support structure, a single-axis tracking system, heat transfer fluid (HTF), a pump, a thermal storage system, and a control system.They work together to efficiently capture and convert solar radiation into usable thermal energy.

The collector is installed in an open area with maximum sunlight. The parabolic mirror is aligned

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along the north-south direction to get the most sunlight. A tracking system keeps the collector pointing towards the sun all day, ensuring the mirror always focuses on the sun for maximum solar collection. Sunlight falling on the parabolic mirror is focused along the focal line, where the receiver tube is placed. The receiver tube is painted with a material that absorbs heat well and is covered with a glass layer to protect it and reduce heat loss. The heat transfer fluid flowing through the receiver tube absorbs the concentrated heat and takes it to a heat exchanger or thermal storage system.

The heated fluid is then used for steam production, electricity generation, industrial heating, or other thermal uses. At the same time, the control system monitors temperature, sunlight intensity, and the tracking system's accuracy to keep the system efficient and running smoothly. The collector is installed in an open area with maximum solar exposure, where the parabolic reflector is aligned along the north-south axis to optimize sunlight concentration. A tracking mechanism continuously adjusts the collector's orientation throughout the day, ensuring that the reflector remains focused on the sun for maximum energy absorption without interruption. Solar radiation falling on the reflective parabolic surface is concentrated along the focal line, where the receiver tube is positioned. The receiver tube, coated with a selective absorbing material and enclosed in a protective glass cover, absorbs the concentrated heat energy while minimizing thermal losses to the surrounding environment. Heat transfer fluid circulating through the receiver tube absorbs the concentrated thermal energy and carries it to a heat exchanger or thermal storage system. The heated fluid can then be utilized for steam generation, electricity production, industrial heating, or other thermal applications. Simultaneously, the control system monitors temperature, solar intensity, and tracking precision to maintain efficient and continuous system performance.

3.1 Principal of Concentration

The concentration mechanism in a parabolic trough collector is used to turn sunlight into high-temperature thermal energy through optical concentration. When parallel rays of sunlight hit the curved parabolic mirror, the mirror is designed to direct these rays to a single focal line where the receiver tube is. The system includes key parts like the parabolic mirror, the receiver tube, selective absorber material, glass cover, support structure, tracking system, and heat transfer fluid circulation. The parabolic mirror is the main part that focuses the light. The receiver tube is placed at the focal line to absorb the concentrated heat. The selective coating on the receiver tube helps absorb heat better and reduces heat loss. The glass cover helps protect the receiver and reduces heat loss to the environment. The support structure keeps the collector in the right shape and position. The tracking system adjusts the collector as the sun moves to capture maximum sunlight all day. As the heat is absorbed by the receiver tube, the heat transfer fluid takes the thermal energy to storage or usage areas like steam production, industrial heating, or electricity production. This system helps collect, transfer, and use solar energy efficiently.

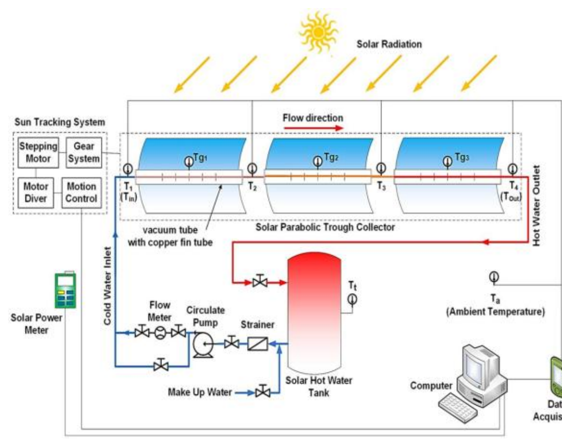

Fig: Parabolic Trough Collector system showing solar concentration, heat transfer fluid circulation, thermal storage, and power/heat utilization process.

IV. COMPONENTS USED

4.1 Mechanical Components

a) Parabolic Reflector: The parabolic reflector is a curved surface made from polished aluminum or silvered glass, designed to capture solar radiation and focus it onto the receiver tube for maximum heat concentration.

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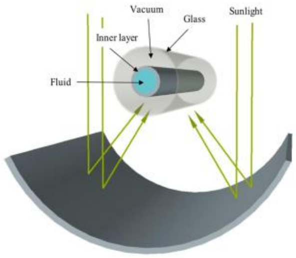

Fig: Parabolic reflector

b) Receiver Tube: The receiver tube is a metal pipe coated with a material that absorbs heat well and is enclosed in a glass cover to collect concentrated solar energy while keeping heat losses to a minimum.

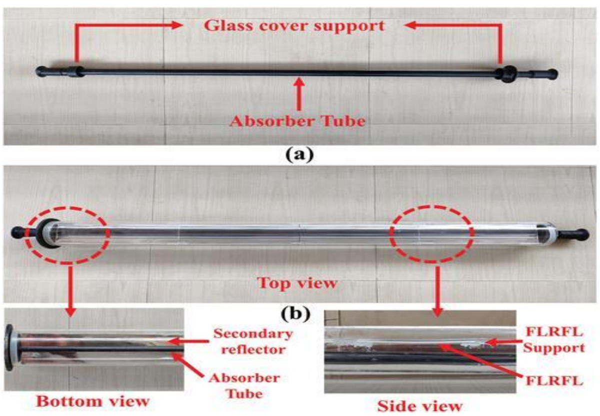

Fig: Receiver tube assembly

c) Support Structure: The support structure provides the mechanical strength and shape to keep the collector in the right form and position under operating conditions.

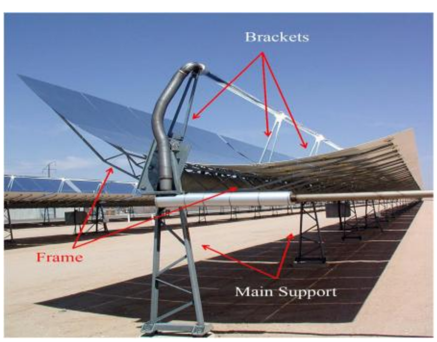

Fig: Support structure

d) Tracking Mechanism: The tracking mechanism continuously adjusts the collector's direction to follow the sun's movement throughout the day, ensuring the maximum solar energy is captured.

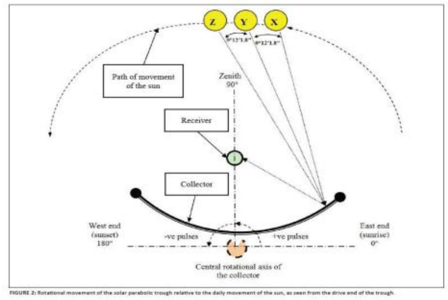

Fig: Single-axis tracking mechanism

4.2 Thermal and Electrical components:

a) Heat Transfer Fluid (HTF): Heat transfer fluid, like synthetic oil, molten salt, or pressurized water, moves through the receiver tube to collect concentrated solar heat and carry thermal energy efficiently for power generation, industrial heating, or storage.

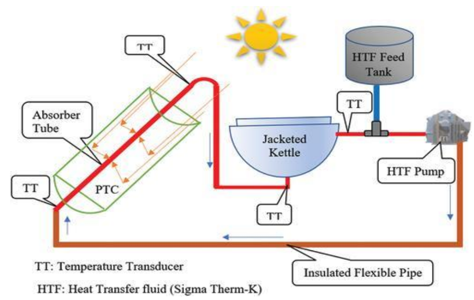

Fig: Heat Transfer Fluid (HTF)

b) Pumping System: The pumping system ensures that the heat transfer fluid keeps moving through the receiver tube and other thermal systems, keeping heat exchange steady and efficient.

c) Thermal Storage Unit: The thermal storage unit holds extra thermal energy made during peak sunlight hours, allowing the system to provide heat or electricity even when it's cloudy or during the night.


Fig: Thermal Storage Unit

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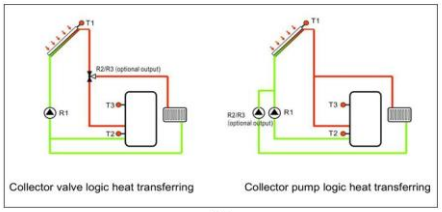
d) Control System: The control system keeps an eye on key factors like temperature, solar tracking angle, fluid flow rate, and overall collector efficiency to make sure the system runs at its best, stays safe, and produces as much energy as possible.



(3)

Fig: Control System

V. THERMAL PERFORMANCE ANALYSIS

The thermal performance of a Parabolic Trough Collector (PTC) depends on how well it converts solar radiation into useful thermal energy while keeping optical and heat losses low. The overall efficiency of the collector is influenced by factors like solar irradiance intensity, reflector surface accuracy, receiver tube absorptivity, tracking precision, ambient temperature, heat transfer fluid properties, and thermal losses from convection and radiation. When solar radiation hits the parabolic reflector, the reflected rays are focused onto the receiver tube, where the absorbed energy heats the circulating heat transfer fluid. The thermal efficiency of the system improves with higher solar concentration ratios, better reflector cleanliness, improved absorber coatings, and reduced heat loss to the surroundings. But things like optical misalignment, Imperfect reflectivity, dust buildup, and environmental conditions can lower system performance. Good thermal insulation, selective absorber materials, and advanced tracking systems help to maximize useful heat gain and ensure continuous high-temperature operation.

Collector Efficiency Equation: $\eta = Q_u / Aa.Ib$

Where:
η = Thermal efficiency of the collector
Q_u = Useful heat energy gained by the heat transfer fluid
Aa = Aperture area of the collector
Ib = Beam solar radiation incident on the collector surface

Higher optical efficiency, improved receiver design, effective thermal storage, and minimized heat losses greatly improve the thermal performance and operational reliability of parabolic trough collector systems.

VI. APPLICATIONS

- Solar thermal power generation
- Industrial steam generation
- Food processing industries
- Water purification
- Enhanced oil recovery
- Air conditioning and cooling

VII. ADVANTAGES

- High thermal efficiency
- Large-scale power generation capability
- Reduced carbon footprint
- Renewable and sustainable
- Suitable for medium/high temperatures
- Long operational life

VIII. LIMITATIONS

- High initial cost
- Requires large land area
- Performance affected by cloudy weather
- Complex tracking systems
- Maintenance of reflective surfaces

IX. RECENT ADVANCEMENTS

Recent studies focus on:
- Nanofluids as HTF
- AI-based solar tracking
- Molten salt storage
- Hybrid solar-fossil systems
- Improved absorber coatings

These developments significantly enhance efficiency and reduce operational costs.

X. WORKING

Mechanical Working: Mechanical Working: The mechanical operation of a Parabolic Trough Collector is based on the coordinated functioning of the parabolic reflector, receiver tube, support structure, and solar tracking mechanism.

The curved reflector continuously concentrates incoming solar radiation onto the receiver tube positioned at the focal line, while the support structure maintains precise geometric alignment for maximum optical efficiency. A single-axis tracking system rotates the collector from east to west throughout the day, ensuring consistent solar alignment and maximizing thermal energy capture.

Thermal and Control System Working: In the thermal and control system, the heat transfer fluid continuously flows through the receiver tube, where it absorbs the concentrated solar heat energy and transports it to heat exchangers, storage units, or power generation systems.

The pumping system regulates fluid circulation, while sensors and control units continuously monitor temperature, solar intensity, flow rate, and tracking position to optimize system efficiency and maintain stable operation. The integrated control system ensures accurate solar tracking, efficient thermal transfer, and reliable energy output under varying environmental conditions.

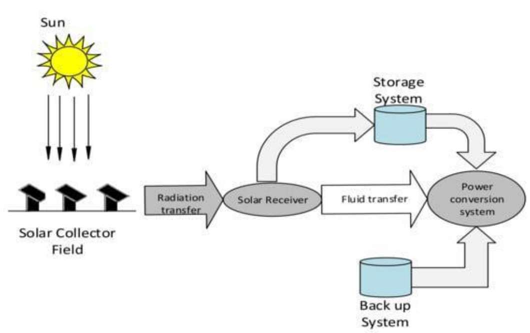


Fig: Block diagram

XI. CONCLUSION

Parabolic Trough Collectors are an effective and proven solar thermal technology for sustainable energy generation. Their ability to produce high-temperature thermal energy with reduced environmental impact makes them ideal for industrial and commercial applications. Although initial costs and tracking complexities remain challenges, ongoing advancements in materials, storage systems, and automation are improving system viability. PTCs are expected to play a critical role in future renewable energy infrastructure

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