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EVALUATION OF THE EFFICIENCY OF PARABOLIC TROUGH SOLAR COLLECTORS

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***ABSTRACT** The growing need for sustainable energy solutions has led to significant advancements in solar energy technologies, with Parabolic Trough Solar Collectors (PTSCs) standing out as a key method for harnessing solar thermal energy. PTSCs utilize parabolically curved mirrors to concentrate sunlight onto a receiver tube, where the solar energy is absorbed and converted into heat. This thermal energy can then be utilized for various applications, such as electricity generation, industrial processes, and heating systems. Despite the potential of PTSCs, their efficiency is limited by several factors, including optical losses, thermal losses, and operational inefficiencies.*

***KEYWORDS:** Parabolic Trough Solar Collectors (PTSCs), Heat transfer fluid (HTF). photovoltaic (PV), or resistance temperature detectors (RTDs).*

1. INTRODUCTION

Solar energy has gained significant attention as a renewable and sustainable energy source. Among the various solar technologies, Parabolic Trough Solar Collectors (PTSCs) have emerged as a highly efficient method for converting solar energy into thermal energy. PTSCs use parabolic mirrors to concentrate sunlight onto a receiver tube, where the solar energy is absorbed and converted into heat. This heat can then be used for a variety of applications, including electricity generation, industrial processes, and residential heating

The development and optimization of PTSCs are crucial for improving the overall efficiency of solar thermal systems. By understanding the mechanisms that influence the performance of PTSCs, researchers and engineers can design more effective systems that maximize energy conversion and minimize losses

The global shift towards renewable energy sources has intensified due to growing environmental concerns and the diminishing reserves of fossil fuels. Among the myriad of renewable energy technologies, solar energy stands out due to its abundance, sustainability, and the minimal environmental footprint associated with its use. Within the spectrum of solar energy technologies, solar thermal energy systems, particularly parabolic trough solar collectors (PTSCs), have garnered significant attention for their efficiency and potential for large-scale energy production.

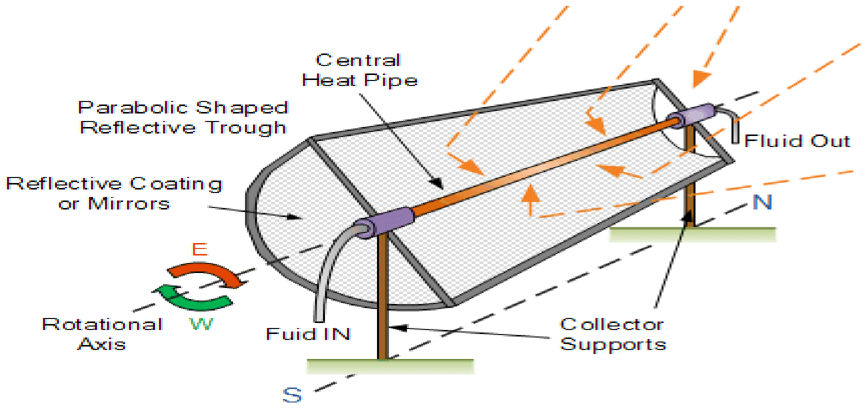


Fig:1.1Components of a Parabolic Trough Solar Collector

2. LITERATURE REVIEW

2.1 History of Solar Energy

Solar energy has been harnessed since ancient times, with various civilizations utilizing the sun’s power for heating and light. The historical development of solar energy technologies can be summarized as follows:

- Ancient Times: The earliest recorded use of solar energy dates back to ancient civilizations such as the Greeks and Romans. The Greeks used passive solar heating techniques in their architecture, orienting their buildings to maximize solar gain. The Romans improved upon these techniques, using solar energy for heating public baths .
- Middle Ages: During the medieval period, the use of solar energy in Europe diminished, but it continued in other parts of the world. In ancient China, solar heating was employed in the design of structures to capture and retain heat.19th Century: The modern era of solar energy began in the 19th century. In 1839, French physicist Edmond Becquerel discovered the photovoltaic effect, which led to the development of solar cells. The concept of solar thermal energy also emerged with the invention of the first solar collector by Augustin Mouchot in 1860, which was used to produce steam for industrial applications

Behzad Shankar et In order to improve the performance of a linear parabolic collector, the thermal effects of using Al_2O_3-syltherm oil nanofluid with different concentrations and new flange-shaped turbulators are investigated. The heat transfer efficiency of the collector can be increased by 5 % for 350 K, 3.5 % for 450 K and 1% for 550 K inlet temperature .

Daniele cocco et al The CSP plants studied herein use thermal oil as heat transfer fluid and as storage medium in a two-tank direct thermal storage system. The performance of the CSP plants was evaluated on the basis of a 1 MWe ORC unit with a conversion efficiency of about 24%. The results of the performance assessment demonstrate that CSP plants based on linear Fresnel collectors lead to higher values of electrical energy production per unit area of occupied land (about 50–60 kWh/y per m^2 vs. 45– 55 kWh/y m^2 produced by solutions based on parabolic troughs) .

Fahim Ullah et al The current study represents the modification of parabolic trough solar collector, with the using of solar tracking tilt sensor with the continuous water circulation rate of 0.22 kg/s to enhance the productivity of the parabolic trough solar collector, and the tracking system consisting of low-speed 12 V motor units of 0.75 r/min and torque of 50 N m was found suitable for the tracking mechanism. The efficiency was noted 31% for the month of August due to the highest absorbing solar irradiance .

Farhad Salek et.al The mathematical model of the proposed system is developed in MATLAB software. In the solar thermal system provided in this paper, the storage tank is employed for extending the working hours of the system leading to improvement of total water generation rate. The maximum rate of water production of proposed system is approximately 400 lit per month in tropical climates with specific energy consumption of 3 kWh/lit .

3. RESEARCH METHODOLOGY

3.1 Research Design

The research design outlines the framework for conducting the study, including the approach, procedures, and techniques used to evaluate the efficiency of parabolic trough solar collectors (PTSCs). This study employs an experimental research design combined with theoretical analysis to assess PTSC performance under various conditions.

- **Objective**: To systematically evaluate the efficiency of PTSCs by analyzing optical and thermal performance.

- **Approach**: The study uses a combination of controlled laboratory experiments and field tests to gather empirical data.
- **Design**: The research involves setting up experimental PTSC systems, collecting performance data, and comparing it with theoretical predictions.

4. EXPERIMENTAL SETUP

4.1 Description of Equipment:The experimental setup for evaluating the efficiency of parabolic trough solar collectors involves several key pieces of equipment. Each component is crucial for accurately measuring and analyzing the performance of the collectors.

- **Parabolic Trough Solar Collector**: The main component of the experiment, consisting of parabolic mirrors that focus sunlight onto a receiver tube. The collector's specifications include:
    - **Mirror Dimensions**: Length, width, and curvature radius.
    - **Receiver Tube**: Material and dimensions, designed to capture and transfer concentrated solar energy.
    - **Tracking System**: An automatic tracking system that adjusts the collector's orientation to follow the sun’s path.
- **Solar Irradiance Sensor**: Pyranometers or radiometers measure the intensity of solar radiation incident on the collector. Key specifications include:
    - **Sensitivity**: Ability to measure different ranges of solar irradiance.
    - **Calibration**: Ensures accurate readings.
- **Temperature Sensors**: Thermocouples or resistance temperature detectors (RTDs) measure the temperatures at various points, including:
    - **Receiver Tube Temperature**: Measures the temperature of the heat-transfer fluid.
    - **Ambient Temperature**: Measures the surrounding air temperature.
    - **Fluid Outlet and Inlet Temperatures**: Measures the temperatures of the fluid entering and leaving the receiver tube.
- **Anemometer**: Measures wind speed, which can affect the performance of the collector. Specifications include:
    - **Measurement Range**: Range of wind speeds it can measure.
    - **Accuracy**: Precision of wind speed readings.
- **Data Logger**: Collects and stores data from various sensors. Features include:
    - **Data Storage Capacity**: Amount of data it can hold.
    - **Sampling Rate**: Frequency at which data is recorded.
- **Flow Meter**: Measures the flow rate of the heat-transfer fluid through the receiver tube. Specifications include:

- **Measurement Range**: The range of flow rates it can accurately measure.
- **Accuracy**: Precision of flow rate measurements.

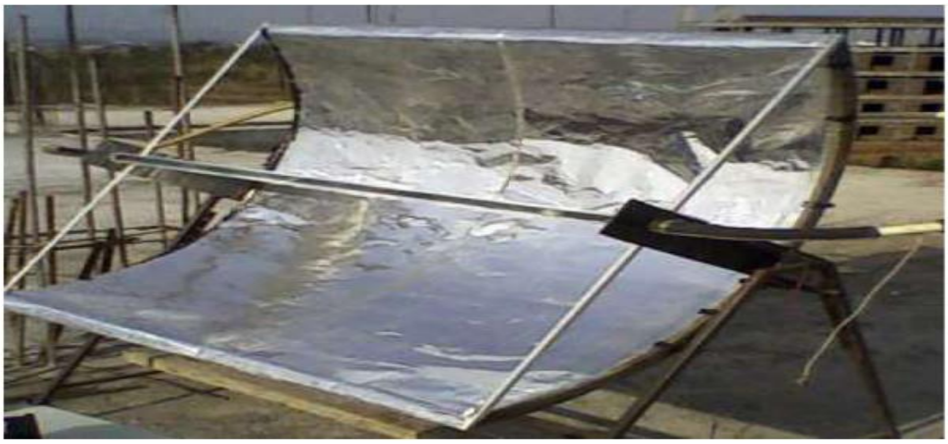


Fig-4.1 Experimental Setup of Parabolic Trough Solar Collectors

5. RESULTS AND ANALYSIS

To Analyze The Impact Of Optical And Thermal Parameters

This objective aims to investigate how factors such as mirror alignment, surface quality, and receiver design influence the optical and thermal efficiency of parabolic trough solar collectors (PTSCs). Below is a detailed breakdown of the results and data analysis for this objective

Data Presentation

Tables:

- Table 5.1: Optical Efficiency with Different Mirror Alignments

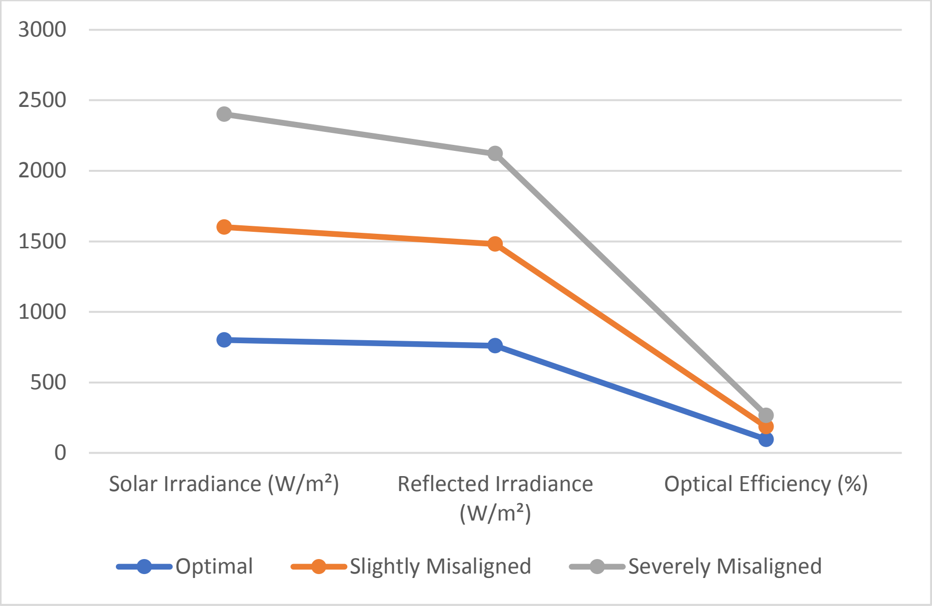
Alignment	Solar Irradiance (W/m²)	Reflected Irradiance (W/m²)	Optical Efficiency (%)
Optimal	800	760	95
Slightly Misaligned	800	720	90
Severely Misaligned	800	640	80

Table 5.2: Thermal Efficiency with Different Receiver Designs

Receiver Design	**Inlet Temp (°C)**	**Outlet Temp (°C)**	**Heat Transfer Rate (W)**	**Thermal Efficiency (%)**
Single Tube	200	300	1000	80
Evacuated Tube	200	320	1200	85
Selective Coating	200	330	1300	90

Graphs and Charts:

Figure 5.1**:** Line Graph of Reflected Irradiance vs. Mirror Alignment



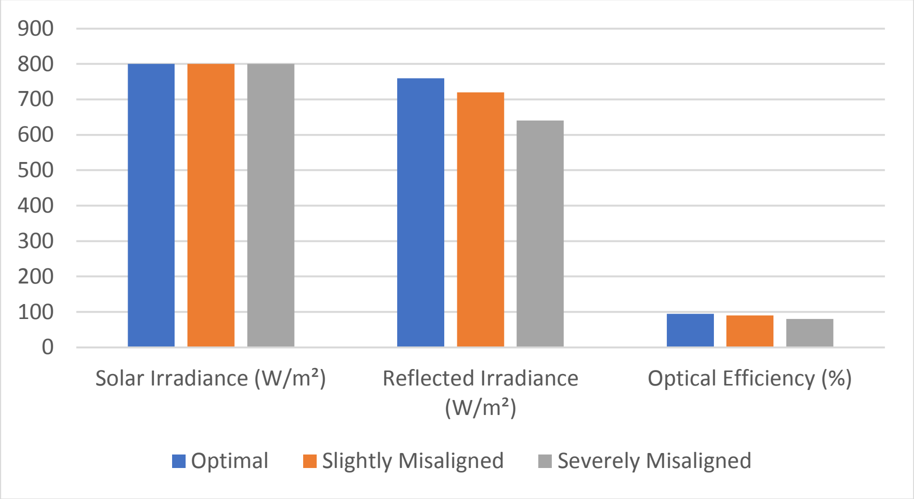
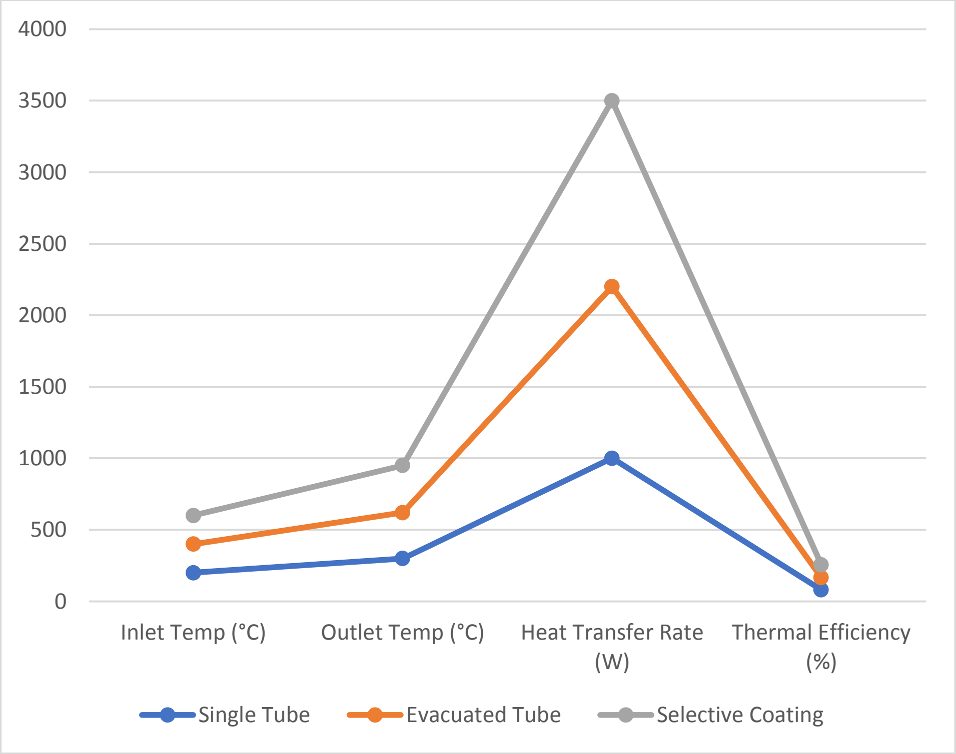


Fig 5.1: Line Graph of Reflected Irradiance vs. Mirror Alignment

Shows how reflected irradiance decreases with increasing misalignment.

Figure 5.2: Bar Chart of Thermal Efficiency for Different Receiver Designs



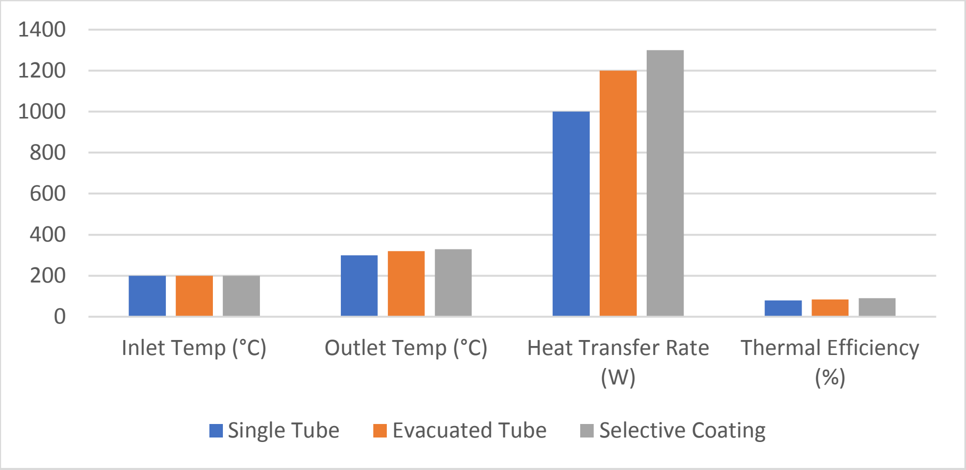


Fig 5.2: Bar Chart of Thermal Efficiency for Different Receiver Designs

TO COMPARE EXPERIMENTAL DATA WITH THEORETICAL MODELS

This objective focuses on evaluating the discrepancies between experimental results and established theoretical models to identify areas for improvement. Below is a detailed breakdown of the results and data analysis for this objective.

Data Presentation

Tables:

- Table 5.3: Optical Efficiency Comparison

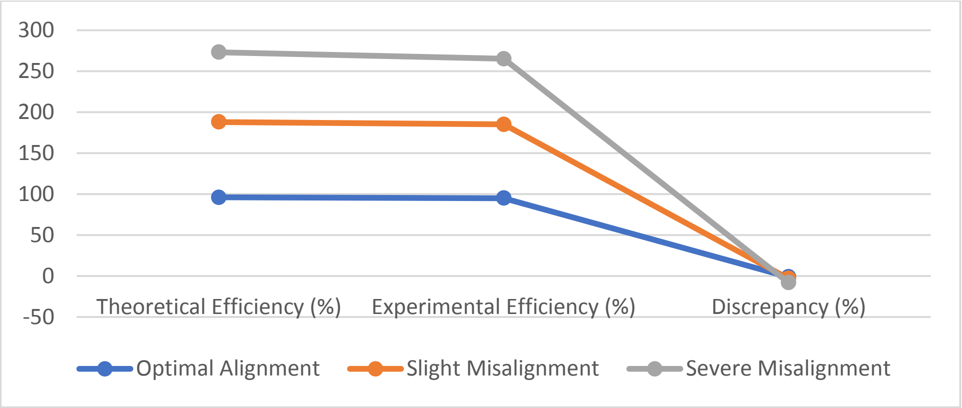
Parameter	**Theoretical Efficiency (%)**	**Experimental Efficiency (%)**	**Discrepancy (%)**
Optimal Alignment	96	95	-1
Slight Misalignment	92	90	-2
Severe Misalignment	85	80	-5

- Table 5.4: Thermal Efficiency Comparison for Different Receiver Designs

Receiver Design	**Theoretical Efficiency (%)**	**Experimental Efficiency (%)**	**Discrepancy (%)**
Single Tube	82	80	-2
Evacuated Tube	87	85	-2
Selective Coating	88	90	+2

Graphs and Charts:

- Figure 5.3: Line Graph of Optical Efficiency: Theoretical vs. Experimental



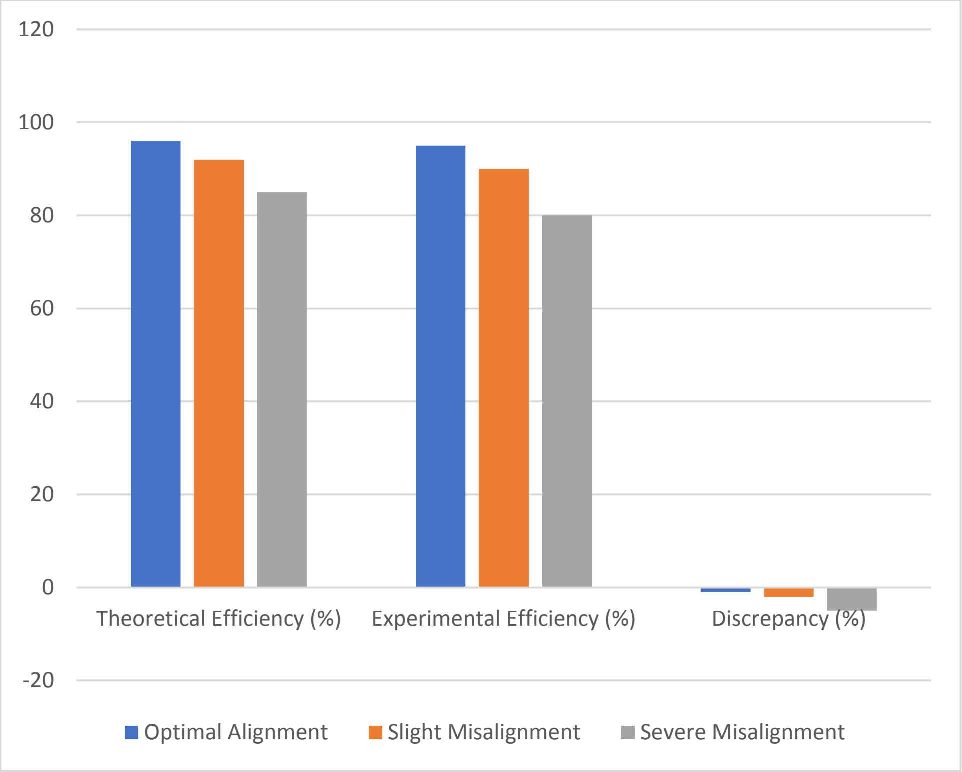
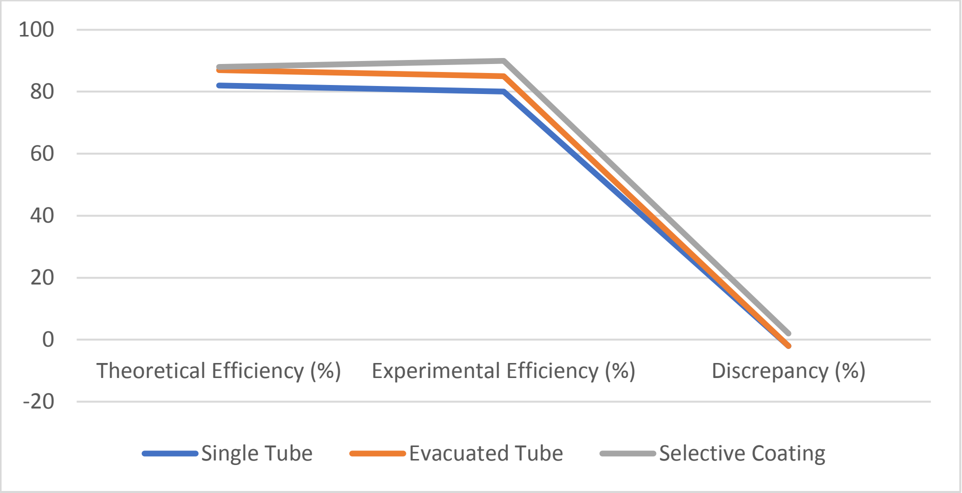


Fig 5.3: Line Graph of Optical Efficiency: Theoretical vs. Experimental

- Plot showing the comparison of optical efficiency between theoretical models and experimental data across different mirror alignments.

Figure 5.3: Bar Chart of Thermal Efficiency for Receiver Designs: Theoretical vs. Experimental



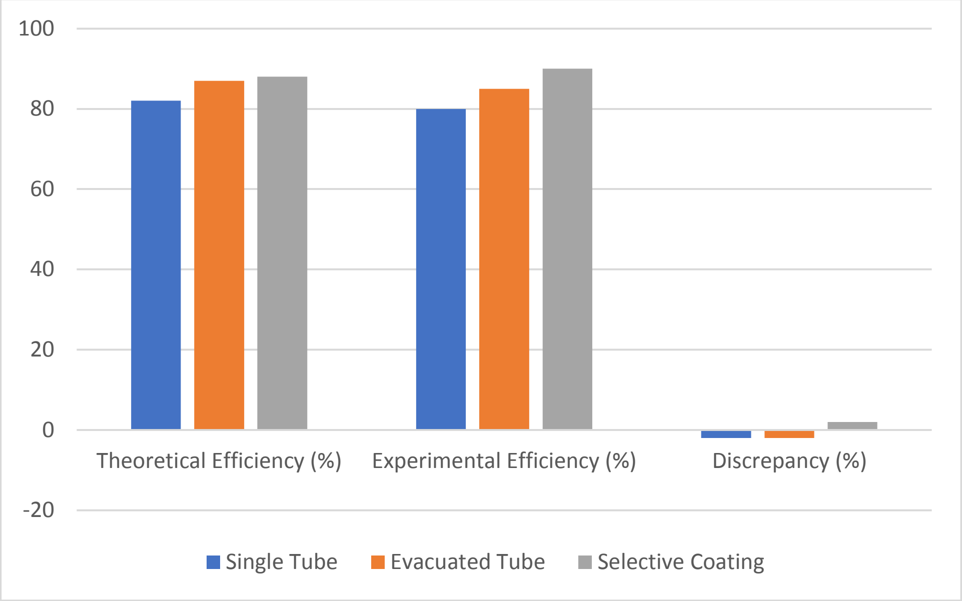


Fig 5.4: Bar Chart of Thermal Efficiency for Receiver Designs: Theoretical vs. Experimental

6. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this section, briefly summarize the key results and insights obtained from the study:

- **Efficiency Metrics**:
  - **Optical Efficiency**: Recap the measured optical efficiency of the parabolic trough solar collectors and how it compares with theoretical predictions and previous studies.
  - **Thermal Efficiency**: Summarize the thermal efficiency results, including the performance of the collector in converting absorbed solar energy into usable heat.
- **Impact of Variables**:
  - **Solar Irradiance**: Highlight the effects of varying solar irradiance on collector efficiency and energy output.
  - **Ambient Conditions**: Summarize how factors such as ambient temperature and wind speed influenced performance.
- **Experimental Insights**:
  - **Performance Trends**: Recap any observed trends, such as daily or seasonal variations in efficiency.

Discrepancies and Validation: Summarize any discrepancies between experimental data and theoretical models, and discuss their implications

6.2 Future Research

- **Foundation for Innovation**: The findings of this study serve as a foundational reference for future research and development in the field of solar thermal technology. By identifying key factors influencing efficiency and proposing design and operational improvements, the study sets the stage for further innovations and advancements.

- **Research Directions**: The study highlights specific areas where additional research is needed, such as advanced tracking systems, high-quality reflective materials, and optimized receiver designs. These identified areas can guide researchers in developing more efficient and cost-effective solar thermal systems.

  Interdisciplinary Collaboration: The insights gained from this research can foster interdisciplinary collaboration among engineers, scientists, and policymakers. By providing a detailed understanding of PTSC efficiency, the study encourages collaboration aimed at overcoming technological challenges and enhancing the deployment of solar thermal energy

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