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Review of Fluids used for Parabolic Trough Solar Collector Receivers

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Abstract

Parabolic Trough Solar Collectors (PTCs) are among the most mature and widely implemented Concentrating Solar Power technologies for electricity generation and industrial thermal applications. These systems use parabolic reflectors to focus solar radiation onto a receiver tube, where a heat transfer fluid (HTF) absorbs and transports thermal energy. The thermo-physical properties, thermal stability, and operating temperature range of the HTF significantly influence system efficiency. Various HTFs, including synthetic oils, molten salts, water/steam, and nanofluids, have been investigated to enhance thermal performance and reduce losses. This review presents the working principles of PTCs, selection criteria for HTFs, heat transfer enhancement techniques, and recent technological advancements. Thermal loss mechanisms, receiver design improvements, and integration of thermal energy storage systems are also discussed. Furthermore, emerging modeling approaches such as Artificial Neural Networks and Adaptive Neuro-Fuzzy Inference Systems are highlighted for performance prediction and optimization. The study identifies key challenges including experimental validation, advanced fluid development, and heat loss characterization. The findings contribute to the development of efficient, reliable, and sustainable solar thermal systems.

Keywords

Concentrating solar power, Heat transfer fluids, Nanofluids, Parabolic trough collectors, Thermal energy storage, Solar thermal systems

1. Introduction

Growing global energy demand and environmental concerns have accelerated the development of renewable energy technologies such as concentrating solar power (CSP). Among CSP technologies, the parabolic trough collector (PTC) is widely adopted due to its technological maturity and high thermal efficiency [1,3]. A PTC consists of a parabolic reflector that concentrates solar radiation onto a receiver tube located at its focal line. The receiver contains a heat transfer fluid (HTF), which absorbs thermal energy and transports it for electricity generation or industrial heating applications [7,14]. The main components include the parabolic reflector, receiver tube, heat transfer fluid, and tracking system. PTC systems typically operate between 100°C and 600°C depending on HTF selection and system design [24]. The performance of PTC systems is influenced by optical efficiency, heat transfer characteristics, thermal losses, and HTF properties [27].

2. Research Contributions

This review synthesizes key research contributions related to heat transfer fluids, enhancement techniques, thermal losses, and performance modeling. Synthetic oils and molten salts provide stable performance at elevated temperatures, while nanofluids improve thermal conductivity and heat transfer efficiency [24,25,]. Passive enhancement techniques such as twisted tape inserts and vortex generators improve heat transfer performance but may increase pressure drop [1,21]. Thermal losses due to conduction, convection, and radiation significantly affect system efficiency, and evacuated receivers help reduce these losses [4, 22]. Advanced modeling techniques including Monte Carlo Ray Tracing, finite volume methods, and artificial intelligence approaches such as ANN and ANFIS are widely used for performance prediction and optimization [11].

3. Technological Advancements

Significant advancements have been made in HTF development, receiver design, thermal energy storage integration, and system optimization. Molten salts provide higher operating temperatures and enable thermal energy storage integration [24]. Advanced receiver coatings improve solar absorption and reduce emissivity losses [17]. Thermal energy storage systems enhance reliability and enable continuous operation during low solar irradiance conditions [5]. Artificial intelligence and numerical simulation tools have improved system design, performance prediction, and operational efficiency [11].

4. Future Challenges

Despite significant progress, several challenges remain. Experimental validation of heat transfer enhancement techniques under real operating conditions is required [4]. Wind-induced convective heat loss requires further investigation and characterization [22]. Development of cost-effective, stable, and environmentally friendly HTFs remains a key research priority [12]. Advanced receiver geometries and intelligent predictive models using artificial intelligence techniques are needed to optimize performance and reduce operational costs [21].

5. Conclusion

Parabolic trough solar collectors represent a mature and efficient solar thermal technology. Heat transfer fluid selection plays a critical role in determining system performance, efficiency, and operating range. Synthetic oils and molten salts are widely used, while nanofluids offer promising performance improvements. Heat transfer enhancement techniques, advanced receiver designs, and thermal energy storage integration significantly improve efficiency. Future research should focus on experimental validation, advanced HTF development, intelligent modeling, and cost reduction to improve commercial viability and large-scale deployment.

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