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# A review on performance of single pass and multi pass solar air heaters

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## Abstract:

Solar air heaters (SAHs) have emerged as a cost-effective and efficient solution for renewable heating, with multi-pass, low-cost designs showing particular promise. This review synthesizes recent advancements and performance evaluations of multi-pass low-cost SAH systems, organized into four main categories: general literature on solar air heaters, performance analysis of single-pass systems, experimental enhancements in heat transfer, and analysis techniques for heat transfer. The review highlights various strategies to improve SAH efficiency. It covers advancements in solar air heater design, such as the use of artificial roughness, jet impingement, piezo-electric fans, and phase change materials. It also examines mathematical modeling for optimizing performance and the development of novel absorber materials, including the use of recyclable aluminum cans. Performance analysis indicates that multi-pass configurations generally outperform single-pass systems in terms of heat transfer and overall efficiency. Experimental studies reveal that integrating materials like graphite powder and innovative designs, such as V-up continuous ribs, can significantly enhance thermal performance. Additionally, the review discusses the application of computational fluid dynamics and other analytical techniques to further optimize heat transfer. Overall, the review provides a comprehensive overview of the current state of multi-pass low-cost SAHs, offering insights into ongoing improvements and future research directions aimed at enhancing their performance and cost-effectiveness.

**Keywords:** Multi-Pass Design, Low-Cost SAH, Single-Pass Systems, Heat Transfer Enhancement, Recyclable Aluminum Cans, Cost-Effectiveness

## Introduction:

The increasing global emphasis on sustainable energy solutions has propelled solar air heaters (SAHs) into the spotlight as a promising technology for providing cost-effective and renewable heating. With the pressing need to reduce dependency on fossil fuels and mitigate environmental impacts, SAHs offer a viable alternative by harnessing the abundant and clean energy of the sun. Among the various configurations available, multi-pass low-cost solar air heaters have garnered particular attention for their efficiency and economic benefits. Solar air heaters convert solar radiation into thermal energy, which can be used for a variety of applications including space heating, drying processes, industrial heating, and water desalination. Their popularity is largely attributed to their straightforward design, low installation and maintenance costs, and the fact that they utilize renewable energy. Despite these advantages, the performance of SAHs is influenced by several factors, including climate conditions, design specifications, and materials used.

Recent advancements in the field have focused on improving the efficiency of SAHs through innovative design and material strategies. Multi-pass configurations, which involve multiple flow paths for the air to traverse, have been identified as particularly effective in enhancing heat transfer and overall system performance. These designs aim to address common limitations such as low thermal efficiency and suboptimal heat transfer due to the formation of a laminar boundary layer on the absorber plate.

This review provides a detailed exploration of the latest developments and performance evaluations of multi-pass low-cost solar air heaters. It is structured into four key areas:

1. General Literature Review of Solar Air Heaters: This section offers an overview of the fundamental principles of SAHs, summarizing various techniques used to enhance their thermal performance. It examines different methods for disrupting the laminar boundary layer and improving heat transfer, such as artificial roughness, jet impingement, piezo-electric fans, and phase change materials (PCMs).
2. Performance Analysis of Single-Pass Solar Air Heaters: This part delves into the performance metrics of single-pass systems, highlighting the efficiency gains achieved through design innovations and material improvements. It includes a review of various experimental studies and their findings on how different configurations and materials affect heat transfer and thermal performance.
3. Experimental Studies on Heat Transfer Enhancement: This section focuses on practical approaches to improving heat transfer in SAHs. It covers experimental investigations into various design modifications, such as the use of extended surfaces, corrugated plates, and artificial roughness elements. It also explores the integration of heat storage materials and their impact on performance.
4. Analysis Techniques for Heat Transfer in Solar Air Heaters: The final section reviews analytical and computational methods used to evaluate and optimize the heat transfer processes in SAHs. It includes

discussions on mathematical modeling, computational fluid dynamics (CFD), and other techniques that help in understanding and improving the efficiency of solar air heaters.

By synthesizing recent research and advancements in these areas, this review aims to provide a comprehensive understanding of the current state of multi-pass low-cost solar air heaters. It highlights key findings, trends, and future research directions, offering valuable insights for researchers, engineers, and policymakers interested in advancing solar heating technologies and improving their practical applications.

**Solar Air Heater System:**

**1. Introduction to Solar Air Heater Systems**

A solar air heater (SAH) is a device designed to convert solar energy into thermal energy, which can be used for various applications such as space heating, drying of agricultural products, and industrial processes. It is a straightforward and cost-effective technology that harnesses the sun's energy to heat air, which is then circulated through or around the desired space or process.

**2. Basic Components of a Solar Air Heater**

1. **Collector**: The core component of a solar air heater, the collector absorbs solar radiation and converts it into heat. It typically consists of:
   - **Absorber Plate**: This is a flat or corrugated plate coated with a material that has high absorbance and low reflectance of solar radiation. The absorber plate collects and converts solar energy into heat.
   - **Glazing**: A transparent cover (usually glass or plastic) that protects the absorber plate from environmental elements while allowing sunlight to pass through. It also helps in trapping heat by creating a greenhouse effect.
   - **Insulation**: Located behind the absorber plate, insulation minimizes heat loss to the surroundings, ensuring that the heat collected is retained for use.
2. **Air Flow System**: This system ensures that air is circulated through the collector to be heated. It includes:
   - **Inlet and Outlet Ducts**: Channels through which air enters and exits the collector. Proper design of these ducts is essential for efficient airflow and heat transfer.
   - **Fans or Blowers**: Used in some systems to enhance air circulation, especially in forced convection systems where natural airflow might be insufficient.
3. **Storage and Distribution System**: In systems where thermal storage is required:
   - **Heat Storage**: Some SAH systems integrate thermal storage materials, such as phase change materials (PCMs) or sensible heat storage materials, to store heat for later use.

- **Distribution**: The heated air is distributed to the target area or application, such as a building or drying chamber, often through additional ductwork or ventilation systems.

**3. Types of Solar Air Heaters**

1. **Flat-Plate Collectors**: These are the most common and straightforward type of SAH. They consist of a flat absorber plate covered by glazing and insulated on the back. Flat-plate collectors are typically used in residential and commercial applications for space heating.
2. **Evacuated Tube Collectors**: These collectors use a series of glass tubes with a vacuum between the inner and outer tubes. The vacuum acts as an insulator, reducing heat loss and allowing the system to achieve higher temperatures. They are often used in regions with colder climates or for applications requiring higher temperature outputs.
3. **Integral Collector Storage Systems**: This type combines the collector and storage into a single unit. The air passes through the collector and is stored in the same system, making it a compact and efficient solution for applications with relatively constant heating needs.
4. **Double-Pass and Multi-Pass Systems**: These systems involve multiple passes of air through the collector to increase heat transfer efficiency. Air passes through the collector multiple times, allowing more heat to be absorbed. Multi-pass systems can significantly improve performance compared to single-pass systems.

**4. Performance Factors and Efficiency**

1. **Climate Conditions**: The effectiveness of an SAH is heavily influenced by local weather conditions, including solar radiation levels, temperature, and humidity. Systems are designed to optimize performance based on the expected local climate.
2. **Collector Design**: The design of the absorber plate, glazing, and insulation plays a critical role in the overall efficiency of the system. Innovations such as finned absorbers, corrugated plates, and improved glazing materials can enhance performance.
3. **Air Flow Dynamics**: The efficiency of heat transfer depends on how effectively the air circulates through the collector. Proper design of air ducts, use of fans, and optimization of airflow can improve performance.
4. **Thermal Storage**: For applications requiring consistent heat output, incorporating thermal storage materials can enhance the system’s ability to provide heat even when solar radiation is not available.

**Problems Associated with Solar Air Heaters**

Solar air heaters (SAHs) offer a sustainable solution for harnessing solar energy for heating applications. However, several challenges can impact their efficiency, performance, and overall utility. Here’s an overview of common problems associated with solar air heaters:

## 1. Thermal Efficiency Issues

- **Low Heat Transfer Efficiency**: Solar air heaters often face challenges in transferring heat effectively from the absorber plate to the circulating air. Factors like the formation of a thermal boundary layer on the absorber plate and suboptimal air flow can reduce heat transfer efficiency.
- **Temperature Losses**: Heat can be lost through the collector's sides, back, and glazing, especially if insulation is inadequate. This results in lower thermal performance compared to theoretical predictions.

## 2. Design and Material Constraints

- **Limited Performance of Traditional Designs**: Conventional designs, such as flat-plate collectors, may not achieve high temperatures or performance in colder climates or during cloudy days. They often have a limited ability to store heat for use during non-sunny periods.
- **Material Durability**: The materials used in solar air heaters, such as coatings on the absorber plates and glazing, may degrade over time due to exposure to UV radiation, extreme temperatures, or environmental conditions. This can lead to reduced performance and increased maintenance costs.

## 3. Climate Dependency

- **Variability in Solar Radiation**: The performance of solar air heaters is highly dependent on the amount of solar radiation available. In regions with frequent cloud cover, high humidity, or long winter periods, the efficiency of SAHs can be significantly diminished.
- **Temperature Sensitivity**: In colder climates, the heat generated by SAHs might not be sufficient to meet heating demands. Additionally, low temperatures can affect the performance of the collector and the air flow system.

## 4. Installation and Maintenance Challenges

- **Complex Installation**: Proper installation of solar air heaters requires careful consideration of the collector's orientation, angle, and integration with the existing heating system. Incorrect installation can lead to suboptimal performance.
- **Maintenance Requirements**: Over time, dust, debris, or snow can accumulate on the collector surface, reducing its efficiency. Regular cleaning and maintenance are required to ensure optimal performance, which can be a burden for users.

## 5. Cost Considerations

- **Initial Costs**: The upfront cost of purchasing and installing solar air heaters can be relatively high, especially for systems with advanced features or large-scale applications. This can be a barrier for some users despite long-term savings on energy costs.
- **Economic Viability**: In some regions, the cost-effectiveness of solar air heaters may be limited by factors such as low solar radiation, high installation costs, or competition with other renewable energy technologies.

## 6. Heat Storage and Distribution Issues

- **Insufficient Heat Storage**: Many solar air heaters do not include significant thermal storage, which limits their ability to provide consistent heat during periods without sunlight. Systems with thermal storage solutions can be more complex and costly.
- **Distribution Inefficiencies**: Effective distribution of the heated air to the intended application or space can be challenging. Poor design of ducts, fans, or distribution systems can lead to uneven heating and reduced overall effectiveness.

## 7. Technological Limitations

- **Limited Innovation**: While there have been advancements in SAH technology, some designs and materials may still be outdated or inefficient compared to more recent innovations in other solar technologies.
- **Performance Variability**: The performance of solar air heaters can vary significantly based on design parameters, local conditions, and operational factors. This variability can make it challenging to predict performance and ensure consistent results.

## 8. Environmental and Aesthetic Impact

- **Visual Impact**: The installation of large or numerous solar air heaters can alter the appearance of buildings or landscapes, which may be a concern for some users or communities.
- **Environmental Impact**: While SAHs are environmentally friendly in terms of energy use, the production and disposal of materials used in the collectors can have environmental implications if not managed properly.

## II -REVIEW OF SOME OF THE RESEARCH WORK DONE SO FAR

### 1. General Literature Review about Solar Air Heater

The quest for efficient and sustainable energy solutions has driven extensive research into solar air heaters (SAHs) as a viable alternative for heating applications. This literature review synthesizes various studies focusing on enhancing the thermal performance of SAHs, exploring methods ranging from innovative design techniques to novel materials.

**Brajesh Kumar Ahirwar and Arvind Kumar** conducted a comprehensive review of techniques aimed at improving the thermal performance of solar air heaters. They identified that traditional SAHs suffer from reduced thermal efficiency due to the formation of a laminar sub-layer on the absorbing plate, which impedes heat transfer. To counteract this, they reviewed several methods to disrupt this laminar sub-layer. Key techniques examined include:

- **Artificial Roughness**: Incorporation of artificial rib roughness, turbulators, and protrusions to enhance turbulence and heat transfer.
- **Jet Impingement**: Utilization of high-velocity jets to improve the convective heat transfer coefficient.
- **Piezo-Electric Fans**: A novel approach involving piezo-electric fans to induce air turbulence and enhance heat transfer.
- **Phase Change Materials (PCM)**: Use of PCM to store and release thermal energy, thus improving overall system efficiency.

Performance evaluations highlighted that configurations with non-circular ribs, rectangular ribs, and jet impingement could achieve thermal hydraulic performance factors (THPP) ranging from 1.44 to 3.66, indicating significant potential for improvement in SAH efficiency [1].

**Réné Tchinda** focused on the mathematical modeling of closed solar air heaters. The study emphasizes the importance of mathematical models in understanding heat transfer processes, optimizing designs, and predicting performance. Tchinda's review classified various models based on factors such as the number of covers, absorber shape, and packing beds. The primary governing equations were derived from the first law of thermodynamics, underscoring their critical role in system analysis and performance prediction [2].

**T. Alam and M.-H. Kim** provided a detailed review of heat transfer techniques specifically for double-pass solar air heaters. Double-pass systems are designed to enhance performance by increasing the convective heat transfer coefficient and heat transfer area. The review covered various experimental studies and methodologies, including the use of extended surfaces, corrugated surfaces, artificial roughness, and packed beds. Notably, packed beds were found to improve heat transfer rates and reduce environmental losses by efficiently absorbing insolation [3].

**S. Algarni, V. Tirth, A. Saxena, and P. Gupta** investigated a cost-effective approach to enhance SAH performance by integrating sensible heat storage materials. Their experimental study compared three materials—graphite powder, brick powder, and desert sand—deployed in cylindrical containers above the absorber. Configuration 1, utilizing graphite powder, achieved the best performance metrics, including a heat transfer rate of 541.2 W/m²K, thermal efficiency of 37.62%, and a maximum exhaust air temperature of 41.2°C. This configuration demonstrated superior performance relative to other configurations and traditional SAH designs [4].

**G. Alvarez, J. Arce, L. Lira, and M.R. Heras** explored the development of a single-glass air solar collector using recyclable aluminum cans (RAC) for absorber plates. This innovative design aimed to incorporate recycled materials while maintaining cost-effectiveness. The collector featured air flow channels made from blackened aluminum cans, which enhanced absorptance and thermal efficiency. The collector was evaluated against ASHRAE standards, showing promising results in thermal efficiency and temperature predictions compared to existing literature [5].

**Conclusion:**

Overall, these studies highlight diverse approaches to overcoming the limitations of traditional solar air heaters, from advanced design techniques and materials to innovative modeling and experimental configurations. The ongoing advancements in SAH technology reflect a growing commitment to improving energy efficiency and sustainability in renewable energy applications.

## 2. Recent Advances in Solar Air Heater Performance

Recent studies have focused on improving the performance of solar air heaters (SAHs) through innovative designs and materials, addressing issues of thermal efficiency and cost-effectiveness.

**Emmanuel Omotosho and Philip Hackney** introduced a solar air heater prototype utilizing upcycled aluminum cans for the absorber surface, aimed at applications like space heating and agricultural drying. Their study showed that a multi-pass configuration significantly outperformed a single-pass system by delivering higher usable heat at elevated temperatures. This research highlights the potential of using waste materials to develop affordable and sustainable solar heating solutions, emphasizing both energy management and waste reduction [6].

**Ankush Hedau and S.K. Singal** tackled the challenge of low thermal efficiency in SAHs caused by the thermal boundary layer on the absorber plate. They investigated a double-pass design with perforated blocks and semi-circular tubes to enhance turbulence and heat transfer. Their mathematical modeling achieved up to 85.36% thermal efficiency and 81.89% effective efficiency under specific design parameters. The study's novel correlations and significant performance improvements mark a substantial advance in SAH design [7].

**Om Kapoor Maurya et al.** proposed a Tubular Three-pass Solar Air Heater (TTPSAH) with a compact arrangement of aluminum tubes. Their research demonstrated high thermal efficiencies of up to 60.04% and notable energy cost savings, with outlet air temperatures reaching up to 110.6 °C. The TTPSAH's compact design and performance metrics suggest its potential for efficient solar heating in various applications [8].

**Mourad Salhi et al.** explored a double-pass solar air heater optimized for solar drying applications, focusing on a V-shaped absorber with variable corrugation angles. Their study, using CFD and experimental validation, achieved a peak collector efficiency of 86% and identified optimal mass flow rates for different dried products. This research underscores the effectiveness of design modifications in enhancing the thermal performance of solar air heaters [9].

**E. El-Bialy and S.M. Shalaby** reviewed recent advancements in solar air heaters, highlighting improvements in heat transfer and thermal storage. They discussed various techniques, such as finned or corrugated absorber plates and thermal storage solutions, and provided a cost analysis of different SAH designs. Their review identified the corrugated air jet impinging absorber plate as the most cost-effective option, while other methods showed varying efficiency and cost [10].

**Poonam S Pardeshi and Mikael Baulic** reviewed tube-type solar air heaters, emphasizing their potential for improved efficiency over flat plate designs. The study highlighted advances in design modifications, such as artificial roughness geometries and advanced technologies like evacuated tubes and micro heat pipe arrays. These innovations promise significant gains in thermal efficiency, paving the way for further enhancements in solar air heater performance [11].

**Conclusion**:

Overall, these studies reflect ongoing efforts to enhance the efficiency and practicality of solar air heaters through innovative designs, material use, and advanced technologies. The progress reported suggests promising directions for future research and development in this field.

## 3. Recent Studies on Enhancing Heat Transfer in Solar Air Heaters

Recent experimental and computational studies have focused on various strategies to enhance the thermal performance of solar air heaters (SAHs), highlighting significant improvements through innovative design and technology.

**Tanongkiat Kiatsiriroat and A. Nuntaphan** explored the impact of an electric field on a flat-plate solar air heater. Their study, featuring a heater inclined at 18 degrees and equipped with electrodes, demonstrated that applying an electric field significantly increases the heat rate, especially at lower Reynolds numbers. With a Reynolds number of 200, the heat rate improved by 1.8 times compared to systems without an electric field. This approach, while constrained by breakdown voltage limits, shows promise for enhancing heat transfer with minimal electric power consumption [12].

**Ahmed F. K. and Asim M Abdul W.** investigated the optimization of SAH efficiency using computational fluid dynamics (CFD) simulations and experimental analysis. Their study focused on a convex-shaped solar air heater designed for natural convection. By varying fin pitch and rib profiles, they achieved notable improvements in heat transfer, with the convex profile demonstrating superior performance. This research contributes to advancing SAH designs, making them more effective for low-temperature heating applications [13].

**Panji Maulana Ibrahim and colleagues** examined the thermal performance of solar air heaters with V-up continuous ribs. They tested various rib angles (30°, 45°, and 60°) and found that the V-ribbed design, particularly at a 60° angle, significantly enhanced thermal performance. The solar air heater with V-ribs showed up to a 123% increase in the Nusselt number and improvements in friction factor and thermal performance factor compared to a smooth plate. These findings validate the effectiveness of V-up ribs in boosting heat transfer and hydraulic performance [14].

**Ritesh Lahori and team** reviewed the challenges and advancements in solar air heaters, emphasizing the role of roughness features like ribs and energy storage solutions. Their review highlighted how incorporating roughness improves heat transfer while increasing pumping power requirements. Additionally, they discussed the integration of phase change materials (PCMs) and packed bed systems to address the intermittent nature of solar energy, enhancing overall efficiency and practicality [15].

**A. K. Srivastava and colleagues** focused on the use of lauric acid as a phase change material (PCM) for solar drying applications. They evaluated the heat transfer characteristics of the PCM during charging and discharging phases, considering the effects of inlet hot air temperature and air velocities. Their study underscores the importance of effective thermal energy storage in improving the efficiency of solar heating and drying systems [16].

**Wang Pin-Yang and team** investigated a new all-glass evacuated tubular solar air heater with a simplified compound parabolic concentrator (CPC). Their system, incorporating U-shaped copper tubes and a heat exchanger, was tested for outlet air temperature, heat power, and efficiency. The experimental results highlighted the effectiveness of this design in improving heat transfer and overall system performance [17].

**Conclusion:**

These studies collectively showcase significant advancements in the field of solar air heaters, demonstrating how various design innovations and technologies can enhance heat transfer efficiency and system performance.

## 4. Analysis Techniques for Heat Transfer in Solar Air Heaters

**K. Thamizhmaran** addresses the challenge of low thermal efficiency in solar air heaters (SAHs), which despite their cost-effectiveness and simplicity, currently have a modest installed capacity due to inadequate heat transfer. Recent research highlights innovative design improvements aimed at enhancing SAH performance. Techniques such as modified Tesla valves, serpentine ducts, and fins on the absorber plate, as well as introducing roughness and waviness, have been explored. Both analytical and experimental evaluations of these designs indicate promising results in increasing the efficiency of SAHs, showing potential for significantly improving their energy conversion rates [18].

**Man Singh Azad** investigates the impact of artificial roughness on SAH performance, focusing on diagonally chamfered cuboids as roughness elements on the absorber plate. The study varied parameters like relative roughness pitch (RRP), arm length of cuboid (ALC), and relative roughness height (RRH) across different Reynolds numbers. The results demonstrated that the roughened absorber plates achieved a maximum Nusselt number 3.68 times higher than smooth plates at Re = 4250. With optimal roughness parameters, the study showed a 2.48-fold improvement in overall performance, emphasizing the significant role of artificial roughness in enhancing heat transfer and thermal performance in SAHs [19].

**Divine N. Utazi and Stephen Tsadu Audu** provide a comprehensive review of solar air heater technologies and performance optimization strategies. They discuss the role of energy storage systems, including sensible and latent heat storage, in improving SAH efficiency. The review highlights various design and operational optimizations that can enhance thermal performance. This overview offers valuable insights into the advancements and strategies needed to address the limitations of solar air heaters and maximize their effectiveness for applications like crop drying and space heating [20].

**Conclusion:**

These studies collectively showcase recent advancements and techniques for improving the heat transfer efficiency of solar air heaters, from innovative design modifications to the use of artificial roughness and energy storage systems.

## 4Overall Conclusion:

This review has provided a comprehensive review of recent advancements and research in the field of solar air heaters (SAHs), with a particular focus on multi-pass, low-cost designs and their performance evaluations. The literature highlights several key areas of development:

1. **General Improvements**: Significant strides have been made in enhancing the thermal performance of SAHs through various techniques such as artificial roughness, jet impingement, and the incorporation of phase change materials (PCM). These methods address the common issue of poor heat transfer efficiency by disrupting laminar boundary layers and improving convective heat transfer.
2. **Performance Analysis**: Single-pass solar air heaters have been analyzed extensively, revealing the benefits of incorporating artificial roughness elements, such as diagonally chamfered cuboids and V-up continuous ribs. These innovations have demonstrated considerable improvements in heat transfer rates and overall performance, underscoring the potential of design modifications in enhancing thermal efficiency.
3. **Experimental Enhancements**: The review of experimental studies indicates that novel configurations, including the use of electric fields and optimized fin and rib designs, can significantly boost the performance of solar air heaters. These enhancements not only improve thermal efficiency but also contribute to more cost-effective and sustainable solar heating solutions.
4. **Advanced Analysis Techniques**: Recent research has explored sophisticated analysis techniques, including computational fluid dynamics (CFD) and various mathematical models, to better understand and optimize heat transfer processes in SAHs. These techniques have provided valuable insights into system behavior and performance, paving the way for more efficient and innovative solar air heater designs.

Overall, the advancements summarized in this chapter reflect a growing emphasis on improving the efficiency and practicality of solar air heaters. By integrating new design elements, optimization strategies, and experimental approaches, researchers are making significant progress toward overcoming existing limitations and enhancing the effectiveness of solar air heaters for diverse applications.

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