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INVESTIGATION OF THERMAL PERFORMANCE AND FLOW CHARACTERISTICS OF RIB-FITTED SOLAR AIR HEATER

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***Abstract*- Solar air heaters (SAHs) are widely used in low-temperature applications; however, their thermal efficiency is limited due to poor convective heat transfer between the absorber plate and flowing air. This study presents an experimental and analytical investigation of the thermal performance and flow characteristics of a rib-fitted solar air heater. Artificial roughness in the form of ribs is employed to enhance turbulence near the absorber surface. Key parameters such as Reynolds number, relative roughness height, and relative pitch are varied systematically. The performance is evaluated in terms of Nusselt number, friction factor, and thermo-hydraulic performance parameter. Results indicate that rib roughness significantly enhances heat transfer compared to a smooth duct, although it increases frictional losses. An optimal combination of rib parameters is identified that maximizes overall efficiency. The findings contribute to the improved design of high-performance solar air heaters.**

***Keywords*- Solar air heater; Artificial roughness; Rib geometry; Heat transfer enhancement; Thermo-hydraulic performance; Reynolds number**

1. INTRODUCTION

The increasing demand for renewable energy technologies has intensified research on solar thermal systems. Solar air heaters are simple in design, economical, and widely applied in space heating and agricultural drying. However, their performance is inherently limited due to the low heat transfer coefficient of air.

To overcome this limitation, artificial roughness is introduced on the absorber plate to disturb the laminar sublayer and enhance turbulence. Rib roughness is one of the most effective techniques, but it also increases frictional resistance, leading to higher pumping power requirements. Therefore, a balance between heat transfer enhancement and pressure drop is essential.

This study focuses on evaluating the combined effect of rib geometry and flow conditions on the thermal and hydraulic performance of a solar air heater.

2. LITERATURE REVIEW

Extensive studies have been conducted on roughened solar air heaters. Artificial roughness in the form of transverse, inclined, and V-shaped ribs has been shown to improve thermal performance significantly.

Previous findings indicate:

- Enhancement in Nusselt number by 1.5–3 times compared to smooth ducts
- Increase in friction factor by 2–5 times
- Strong dependence on rib height, pitch, and flow Reynolds number

Despite these improvements, optimization of rib parameters remains a critical challenge.

3. EXPERIMENTAL SETUP AND METHODOLOGY

3.1 EXPERIMENTAL SETUP

The experimental setup consists of a rectangular duct solar air heater with the following components:Figure 1.1 illustrates the primary components that make up a flat plate collector. These components are as follows:

- Absorber plate fitted with artificial ribs
- Transparent glass cover
- Insulated duct casing
- Centrifugal blower for air flow
- Measuring instruments for temperature, velocity, and pressure

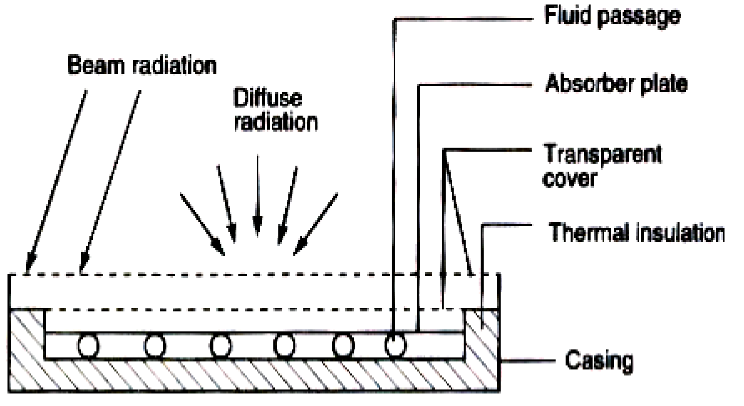

Fig. 1.1 Principal elements that make up the flat plate collector

3.2 RIB GEOMETRY PARAMETERS

The rib roughness is characterized using:

- Rib height (e): 0.5–2 mm
- Rib pitch (p): 5–20 mm
- Relative roughness height (e/D): 0.02–0.05
- Relative pitch (p/e): 8–15

3.3 INSTRUMENTATION AND MEASUREMENTS

- Thermocouples for temperature measurement
- Anemometer for air velocity
- Inclined manometer for pressure drop
- Pyranometer for solar radiation

3.4 DATA REDUCTION AND ANALYSIS

Reynolds Number:

$$Re = \frac{\rho V D}{\mu}$$

Nusselt Number:

$$Nu = \frac{hD}{k}$$

Friction Factor:

$$f = \frac{2\Delta P D}{\rho L V^2}$$

Thermal Efficiency:

$$\eta = \frac{\dot{m} C_p (T_o - T_i)}{IA}$$

Thermo-Hydraulic Performance Parameter:

$$THPP = \frac{(Nu_r/Nu_s)}{(f_r/f_s)^{1/3}}$$

4. RESULTS AND DISCUSSION

4.1 EFFECT OF REYNOLDS NUMBER

The Nusselt number increases with Reynolds number due to enhanced turbulence and improved convective heat transfer. However, the rate of increase reduces at higher Reynolds numbers.

4.2 EFFECT OF RIB GEOMETRY

- Increasing rib height enhances heat transfer but also increases friction losses
- Decreasing pitch improves turbulence generation up to an optimum value
- Best performance observed at moderate values of relative roughness parameters see Fig. 1.2

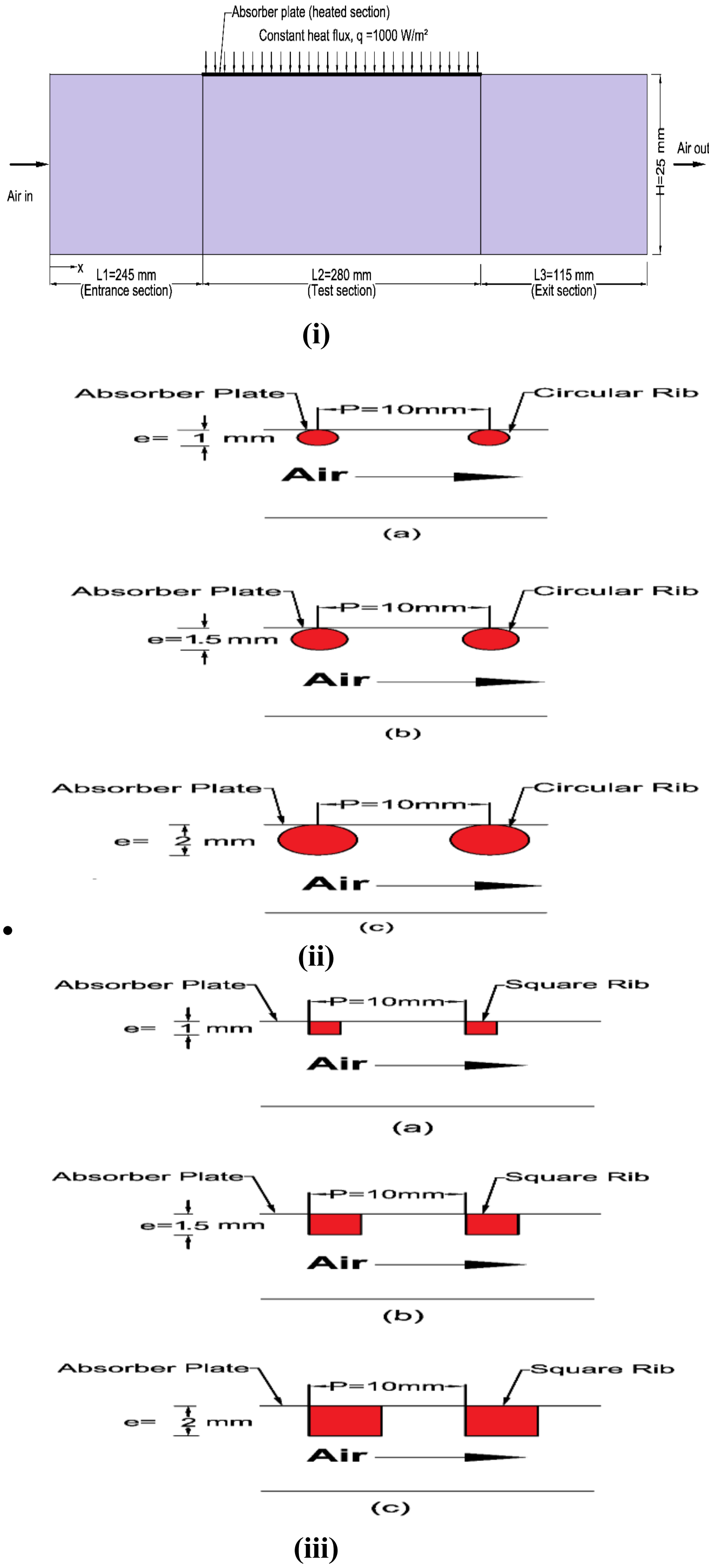

Fig. 1.2 (i) Computational Domain (ii) with circular rib (iii) with square rib

4.3 FRICTION FACTOR ANALYSIS

The friction factor for roughened ducts is significantly higher than that of smooth ducts. It decreases with increasing Reynolds number due to reduced relative influence of surface roughness.

4.4 THERMO-HYDRAULIC PERFORMANCE

The thermo-hydraulic performance parameter indicates that:

- Maximum performance occurs at moderate Reynolds numbers
- Optimal rib configuration balances heat transfer enhancement and friction penalty

5. CONCLUSION

This study demonstrates that artificial rib roughness significantly improves the thermal performance of solar air heaters. The key findings are:

- Heat transfer enhancement of 20–40% compared to smooth duct
- Increase in friction factor is unavoidable but manageable
- Optimal parameters:
- Relative roughness height ≈ 0.03
- Relative pitch ≈ 10

The results confirm that rib roughness is an effective technique for improving solar air heater efficiency when properly optimized.

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