A Review on Analysis of solar air heaters having Artificial Roughness

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Abstract: Solar air heater is the cheapest and extensively used solar energy collection device for drying of agricultural products, space heating, seasoning of timber and curing of industrial products. The use of an artificial roughness on a surface is an effective technique to enhance the rate of heat transfer to fluid flow in the duct of a solar air heater. Use of artificial roughness in solar air heater has been topic in research for the last thirty years. In the present article an attempt has been made to present holistic view of different kinds of roughness geometry used for creating artificial roughness in solar air heater for performance enhancement by experimental approaches. In this article thirty eight experimental studies have been reported on solar air heater, roughened with different kinds of roughness geometry. However, no comprehensive comparative study has been carried out or found in the literature so far, in order to investigate the relative performance of different types of artificially roughened solar air heater. The objective of this article is to perform such a study. Correlations for heat transfer and friction factor, developed by various investigators for artificially roughened solar air heaters have been reported in this report. The effects of various rib parameters on heat transfer and fluid flow processes are also discussed.

Introduction

In our nature, we have abundant amount of solar energy, which may be extensively used as an energy source. So among research community in the world, solar energy utilization for society has become one of the most important issues. Solar air heater is one among solar thermal systems which is extensively used for heating purposes like drying of crops, space heating, winter home heating, seasoning of timber, etc. In rectangular solar air heater duct, heat is transferred from the heated wall (top surface of duct) comprising the absorber plate to incoming air and the other walls are kept insulated. In solar air heater, the heat transfer coefficient between heated absorber plate and working medium, air, is poor which leads to lower efficiency of the solar air heater. The efficiency of the solar air heater increases when the artificial roughness is provided on the absorber plate. Artificial roughness thus provided penetrates the viscous sub layer which increases the intensity of turbulence in the duct and causes enhancement in heat transfer from the roughened surface as compared to smooth surface.

Recent Research Articles

In the research area of solar air heater, many researchers have proposed various artificial roughness geometries for the enhancement of heat transfer rate. In the literature given in this paper, various designs suggested by researchers are discussed. Vipin B. Gawande and his co-workers [3] experimentally investigated convection heat transfer in solar air heater with reverse L-shaped ribs. The experimental and two dimensional CFD analysis of an artificially roughened solar air heater reverse L-shaped rib roughness on the absorber plate has been carried out in the present paper. The effect of relative roughness pitch and Reynolds number on heat transfer enhancement and flow friction characteristics is studied. The main out comings of the experimental investigations are:

![Figure 1. Variation of average Nusselt number for different values of relative roughness pitch and for fixed value of relative roughness height versus Reynolds number.](image-url)

(1) The average Nusselt number increases with the...
increase in Reynolds number. The average Nusselt number increases with the decrease in relative roughness pitch (P/e) at constant relative roughness height (e/D).

2. The maximum enhancement in Nusselt number has been found to be 2.827 times over the smooth duct corresponding to relative roughness pitch (P/e) of 7.14, relative roughness height (e/D) of 0.042 at Reynolds number (Re) of 15,000 in the range of parameters investigated.

3. The average friction factor decreases with the increase in Reynolds number. The average values of friction factor increases as the relative roughness pitch decreases for a fixed value of relative roughness height.

4. The maximum enhancement in the friction factor has been found to be 3.424 times over the smooth duct corresponding to relative roughness pitch (P/e) of 7.14, relative roughness height (e/D) of 0.042 at Reynolds number (Re) of 3800 in the range of parameters investigated.

5. The value of thermo-hydraulic performance parameter which is used for the prediction of optimum reverse L-shaped rib configuration in the system under analysis lies between 1.62 and 1.90 for the range of parameters investigated.

6. The optimum value of thermo-hydraulic performance parameter for reverse L-shaped rib configuration for the range of parameters investigated in the present system has been found to be 1.90 corresponding to relative roughness pitch (P/e) of 7.14, relative roughness height (e/D) of 0.042 and Reynolds number of 15,000. So, the present model can be employed for heat transfer augmentation.

Kalpana Chauhan and his co-workers [06] experimentally investigated Performance evaluation of solar air heaters having v-down discrete rib roughness on the absorber plate. The thermo-hydraulic performance of roughened duct solar air heater with 60° v-down discrete rib roughness on air flow side of absorber plate has been studied using a mathematical model for a range of ambient, design and flow rate parameters (Ta ¼ 273– 303 K, hw ¼ 5 and 20 Wm_2 K_1, 1 ¼ 500, 800, 1000 Wm_2, b ¼ 0.07, G ¼ 0.01–0.06 kg s_1 m_2, and e þ ¼ 10). The important findings of the study are:

1. At low mass flow rates (G _ 0.04 kg s_1 m_2), roughened duct solar air heaters give significant enhancement in thermal efficiency as compared to a smooth duct solar air heater. At these flow rates, the thermal and effective efficiencies differ marginally only.

2. At high flow rates, the effective efficiency is significantly lower than thermal efficiency because of a significant increase in pumping power with increase in the flow rate.

3. At G z 0.045 kg s_1 m_2, the effective efficiency of the roughened and smooth duct solar air heaters is practically the same.

4. When pumping power is not of much concern, roughened collector with the highest relative roughness height is recommended for all operating conditions.

5. For high wind velocity conditions, collector with selective coating on the absorber plate is recommended because its thermal efficiency is only marginally affected with change in the wind velocity.

Anil Kumar and his co-workers [09] did A numerical investigation on various V-pattern rib-roughened air channel has been conducted for determination of overall thermal performance on the basis of Nusselt number and friction factor ratios. The following conclusions are drawn:

1. The use of different rib roughness in the form of V-pattern rib, protrusion rib in V-pattern, dimpled rib in V-pattern, and V-pattern rib with grooves on a heated wall is an valuable technique to augment the local heat transfer.

2. The turbulent fluid stream and wall heat transfer outcome were obtained using CFD with the RNG keε model, and consistent heat flux thermal boundary situations were functional to all the heated walls. The inconsistency between available experimental outcome and the current numerical outcome is less than ±10%. It can therefore be concluded that the current numerical results are reasonably satisfactory.

3. The overall thermal performance based on stable pumping power necessity has been adopted for the optimization of rough and flow parameters for rib-roughened air channel. The objective was to find the optimal V-pattern rib arrangement for both augmenting the heat transfer rates and reducing the pressure loss penalty.
4. The dimpled rib and protrusion rib in transverse pattern enhances the heat transfer by fluid separation and generation of vortices on the upstream and downstream of rib and reattachment of fluid in inter-rib spaces. Angling of transverse rib roughness enhances the heat transfer due to drive of vortices along the rib and creation of a secondary flow cell near the leading end which results in local wall turbulence.

5. The dimpled rib and protrusion rib in V-pattern of a long angled rib helps in the formation of two secondary flow cells as related to single in case of inclined rib resulting in higher heat transfer rate. The creation of grooves in V-pattern rib is found to improve the heat transfer by breaking the secondary flow and producing higher levels of turbulence in the fluid downstream of the V-pattern rib and grooves.

6. Four different rib roughness configurations were included: Simple V-pattern rib, Dimpled rib in V-pattern, Protrusion rib in V-pattern and V-pattern rib with grooves. Among the different V-pattern rib shapes analyzed, a heated plate with V-pattern rib with grooves had the best overall thermal performance. Therefore, the use of V-pattern rib with grooves is recommended to provide surface roughness for air channels.

The recovery dryer was within the drying rate of the main dryer for hybrid and thermal mode drying operation. The novelty of the recovery dryer developed the overall drying efficiency of the hybrid drying system in hybrid and thermal mode operation by 25.84% and 29.7%, respectively. It is evident from the results and the performance evaluation of the system that the recovery dryer, therefore, enhanced the hybrid drying system performance.

**Conclusion**

The common practice in the hybrid solar dryers which are backed up with thermal source is to exhaust the flue gas to the ambient. This flue gases are still hot and carry considerable amount of thermal energy as waste. In the present work, the thermal energy of flue gas from a biomass thermal backup unit was utilized in terms of heat recovery criteria. A prototype of hybrid solar-thermal drying system was coupled with recovery dryer to yield a combination of the main dryer and the recovery dryer. The combination was investigated experimentally to evaluate the enhanced performance compared to the system without recovery. The investigations were conducted under two operational modes, hybrid mode (day and night) and thermal mode alone (night). Red chili was utilized as drying material. The results of the thermal mode showed that the overall drying efficiency of the dryer was increased from 9.9% without recovery dryer to 12.9% with the recovery dryer. The overall drying efficiency of the hybrid drying without recovery dryer was 10.3%, while it was increased to overall drying efficiency of 13% in the case of using hybrid dryer and recovery. The enhancement of the overall drying efficiency due to the recovery dryer was 25.84% in the hybrid day and night drying, and was 29.7% in the night thermal drying mode. This validated enhancement encourages the use of sub dryer as thermal recovery to optimize the utilization of fuel, and to increase the system capacity.

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**References**


