Proceedings of the International Symposium on Sustainable Systems and Technologies, v3 (2015)

Role of Artificial Roughness in Solar Air Heaters

Abdul-Malik E. Momin Sana'a University, dramalikmomin@yahoo.com
Valerie M. Thomas Georgia Institute of Technology, valerie.thomas@isye.gatech.edu

Abstract. Solar air heaters have substantial potential for use in building space heating and for drying of agricultural products. Barriers to their wider use include lack of awareness of the cost-effectiveness of solar air heating and solar drying systems, the lack of technical information, and the lack of local practical experience. The growing number of installations and commercial applications are beginning to overcome these barriers. Nevertheless, improvements in design and technology may be able to improve efficiency and the scope for application. Heat transfer efficiency is one potential area of improvement. Here we address the potential for artificial roughness to improve heat transfer efficiency in solar air heaters. Specifically, the effect of v-shaped ribs are examined and shown to be superior to inclined ribs and to flat surfaces. Adoption of artificial roughness, as well as other design improvements, has the potential to increase the efficiency and range of application of solar air heaters.

Introduction. Solar energy can provide low temperature heat for water heating, saline water distillation, air heating, space heating and crop drying. Flat plat collectors can be designed for applications requiring energy delivery at low to moderate temperatures, up to 100°C and more above ambient temperatures.

Objectives. The objectives of this work is to indicate the current status of solar air heater applications, and to highlight the potential for improved design through an example of the potential benefits of artificial roughness.

Status of Solar Air Heating The drying of agricultural products has been identified as an attractive application for solar air heating, with the potential to displace fossil-fueled crop dryers particularly in for operating conditions of less than 50°C, and a market of 300-900 PJ/year has been estimated (IEA 2006). Trials at large-scale commercial applications were carried out for coffee drying, coir pith drying, moyu drying, and tobacco drying (IEA 2006). In the United States, the California Air Resources Board has supported crop drying demonstrations at commercial farms for prunes, walnuts, pecans, and herbs (Xiarchos and Vick 2011).

Proceedings of the International Symposium on Sustainable Systems and Technologies (ISSN 2329-9169) is published annually by the Sustainable Conoscente Network. Jun-Ki Choi and Annick Anctil, co-editors 2015. ISSSTNetwork@gmail.com.

Cite as: Role of Artificial Roughness in Solar Air Heaters, *Proc. ISSST*, A. E. Momin and V. M. Thomas. http://dx.doi.org/10.6084/m9.figshare.1507571 v3 (2015)

Solar air heating is also used to heat buildings and is increasingly used in the United States, with reported reductions of building heating requirements of 20-30% (Mauthner and Weiss, 2014).

Heat Transfer Because the heat transfer coefficient in a solar air heater is very low, several methods have been employed for improving the heat transfer coefficient. Surface roughness is one of the first techniques to be considered as a means of augmenting forced convection heat transfer. In order to attain higher convective heat transfer coefficient it is desirable that the flow at the heat transfer surface should be turbulent. However, the turbulence created in the core can increase the fan power exorbitantly. It is therefore, desirable that the turbulence must be created only very close to the heat transfer surface, i.e. in the laminar sub-layer only, where the heat exchange takes place. This can be achieved by using artificial roughness with roughness height being such that it does not project into the core but is of the height that just project out of laminar sublayer. Several methods including the use of fins, artificial roughness and packed beds in the ducts have been proposed for the enhancement of thermal performance (Gupta 1993; Hans et al. 2010; Kumar et al. 2013; Liu et al. 1984; Momin et al. 1998, 2002a, 2002b, 2005; Momin 1999; Prasad and Saini 1988, Prasad and Mallick 1983). The use of artificial roughness in solar air heaters owe their origin to several investigations carried out in connection with the enhancement of heat transfer in nuclear reactors and turbine blades. Several investigations have been carried out to study the effect of artificial roughness on heat transfer and friction factor for two opposite roughened surfaces and the correlations were developed by different investigators. The application of artificial roughness in the form of fine wires on the heat transfer surface has been recommended to enhance the heat transfer coefficient by several investigators (Sukahatme 1985).

Artificial Roughness Because the heat transfer coefficient is very low in smooth flat plate collectors, several methods have been employed for improving the heat transfer coefficient. Both artificial roughness and fins are also employed in solar collectors for the enhancement of heat transfer.

The basic shape of the V-shaped roughness element used as artificial roughness lies in its shape formed by two pieces of inclined rib placed to form V-shape. The rib is specified by the following parameters:

1. Roughness height (e): This height is determined by the size or diameter of the copper wire used.
2. Roughness pitch (p): The spacing between adjacent ribs determines the pitch.
3. Angle (α): The included angle between the two rib pieces forming the V.

The actual rib shape parameters must be expressed as non-dimensional parameters for the purpose of developing general heat transfer and fluid friction relationships. The collector system parameter used for the non-dimensional rib shape parameter is the equivalent diameter (D_h) of the duct. The range of parameters has been based on practical considerations of the physical system and operating conditions. The non-dimensional parameters used to describe the V-shaped roughness are:

- (i) Relative roughness height (e/D_h): the ratio of actual rib height to the equivalent diameter of the duct.
- (ii) Relative roughness pitch (p/e): the ratio of actual pitch to the actual height of the roughness elements.
- (iii) Angle of attack (α): the angle between the direction of actual flow stream and the V-rib element.

The basic flow parameter employed is the non-dimensional flow velocity i.e. the flow Reynolds number (Re). We also use the Nusselt number, which is the ratio of convective to conductive heat flow across a boundary; a low Nusselt number close to one is characteristic of laminar flow, whereas a larger number is characteristic of more active convection, and with turbulent flow for Nusselt numbers in the range of 100-1000.

Symbols

D_h	hydraulic diameter of the duct (m)	
e/D_h	relative roughness height	
Nu	Nusselt number	-
p/e	relative roughness pitch	
Re	Reynolds number	
α	Angle of attack of flow (degrees)	
Pr	Prandtl number (0.75 for air)	

We estimate the Nusselt number for smooth surfaces from the Dittus-Boelter equation,

$$Nu = 0.023(Re)^{0.8}(Pr)^{0.4} \qquad \text{Eqn. 1}$$

Data for inclined ribs are from Gupta (1993). Data for v-shaped ribs were developed by Momin (1999).

Results. Figure 1 shows the Nusselt number for smooth surface, inclined ribs, and v-shaped ribs. The figure shows that in all cases the Nusselt number increases as the Reynolds number increases, and that the inclined ribs and v-shaped ribs increase at a faster rate.

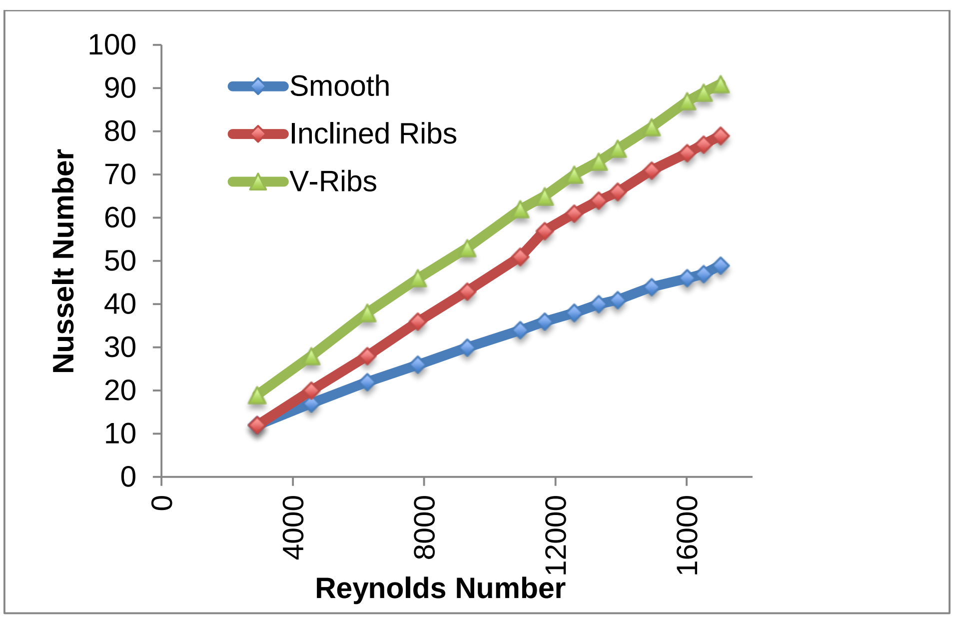

Figure 1: Effect of Surface Roughness on Air Flow Characteristics.

Discussion. Solar air heaters are increasingly deployed, yet they are not yet widely known as a solar technology option. Moreover, there is very little research on opportunities for improved designs and efficiency. As indicated by the results shown here for artificial roughness, there may be opportunities for considerable improvement through research and improved designs.

References

Gupta, D. 1993. Investigation of Fluid Flow and Heat Transfer in Solar Air Heaters with Roughened Absorbers. *Ph.D. Thesis*, Deptt. of Mech. & Industrial Engineering University of Roorkee.

Hans, V.S., Saini, R.P. & Saini, J.S. 2010. Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs. *Int. Journal of Solar Energy*, Elsevier, Vol. 84. 898-911.

IEA (International Energy Agency), 2006. Solar Crop Drying. Solar Heating and Cooling Program. Task 29. http://task29.iea-shc.org Accessed May 8 2015.

Kumar, A., Saini, R.P. & Saini, J.S. 2013. Experimental investigation on thermo-hydraulic performance due to flow attack angle in multiple V-ribs with gap in a rectangular duct of solar air heaters. *Journal of Sustainable Energy & Environment,* Vol. 4, Issue 1, 1-7.

Liu, Y.D., Diaz, L. A. & Suryanarayana, N.V. 1984. Heat Transfer Enhancement in Air Heating Flat-Plate Solar Collectors", Trans. of the ASME *Journal of Solar Energy Engineering*, 106, pp. 358-363.

Mauthner, F. and Weiss, W. 2014. Solar Heat Worldwide 2012: Markets and Contribution to the Energy Supply. International Energy Agency, Solar Heating and Cooling Programme. http://www.solarthermalworld.org/sites/gstec/files/story/2014-10-01/2014_solar_heat_worldwide.pdf

Momin, A. E., Saini, J.S. & Solanki, S.C. 1998. Heat Transfer and Friction Factor Correlations for V-shaped Roughness Elements on the Absorber Plate of Solar Air Heaters. Proc. *International Conference on Energy Research and Development (ICERD*), State of Kuwait, November 9-11.

Momin A. E. 1999. Thermo-Hydraulic Performance of Solar Collector using Artificial Roughness. *Ph.D. Thesis,* Dept. of Mech. & Industrial Engineering, University of Roorkee.

Momin, A. E., Saini, J.S. & Solanki, S.C. 2002a. Heat Transfer and Friction in Solar Air Heater Duct with V-shaped Rib Roughness on Absorber Plate. *Int. Journal Heat and Mass Transfer*, 45, 3383-3396.

Momin, A. E., Saini, J.S. & Solanki, S.C. 2002b. Thermo-Hydraulic Performance of Roughened Solar Air Heaters. Proc. *International Conference on Energy Research and Development (ICERD-2*), State of Kuwait, pp. 807-814. April 8-10.

Momin, A. E., Saini, J.S. & Solanki, S.C. 2005. Enhanced Heat Transfer in Solar Air Heaters. Proc. *International Conference on Energy Research and Development (ICERD-3*), State of Kuwait. Nov. 21-23.

Prasad, B. N. & Saini, J.S. 1988. Effect of Artificial Roughness on Heat Transfer and Friction Factor in a Solar Air Heater. *Solar Energy*, 41, No. 6, pp. 555-560.

Prasad, K. & Mullick, S.C. 1983. Heat Transfer Characteristics of a Solar Air Heater used for Drying purposes. *Applied Energy*, 13, pp. 83-93.

Sukahatme, S.P. 1985. Heat Transfer from Rectangular Vertical Fin Arrays. *Current Research in Heat and Mass Transfer*, A Compendium and A Festschrift for Professor Arcot Ramachandran, ISHMT, Dept. of Mechanical Eng. IIT, Madras, pp.245-258.

Xiarchos, I. and Vick, B. 2011. Solar Energy Use in U.S. Agriculture: Overview and Policy Issues. US Department of Agriculture. http://www.usda.gov/oce/reports/energy/Web_SolarEnergy_combined.pdf