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Investigation of Thermal Performance of Solar Air Heater Using Half Rhombus

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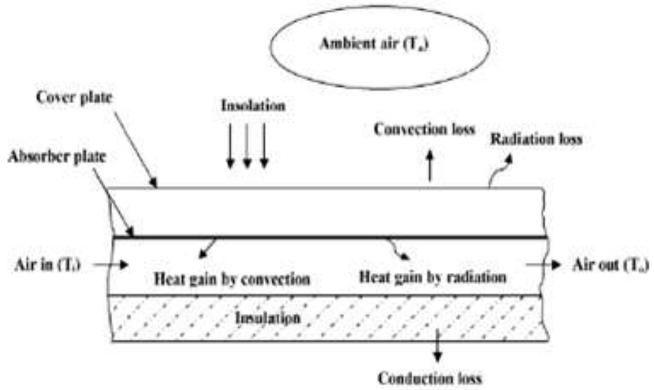
Abstract*—Energy is required to sustain our life. Ventilating your home during normal days can save your money, except in the summer. Ventilation creates a wind chill effect that cools your body. Ventilation cooling is usually combined with energy conservation measures like shading provided by trees and window treatments, roof reflectivity (light-colored roof). Forced air circulation can be used along with natural ventilation in order to increase comfort. Ventilation provides other benefits besides cooling, like fresh air to breathe. Indoor air pollutants tend to accumulate in homes with poor ventilation. Natural ventilation relies on the wind and the "chimney effect" to keep your home cool. The wind will naturally ventilate your home by entering and leaving windows, depending on the wind direction. Heat accumulated in your home during the day can be flushed out by the cool night air. Wind moving over the wall creates a vacuum that pulls air out of the windows. The chimney effect occurs when cool air enters the first floor or basement. The cool air entered, absorbs heat in the room, rises, and exits through ventilating windows. This creates a partial vacuum, which pulls more air through lower-level windows.The energy resources available on the earth are in various forms like sunlight, fossil fuels, hydraulic energy, wind energy, tidal energy, geothermal energy and nuclear energy resources etc. Energy resources may be classified in two ways i.e. conventional and non-conventional energy resources. Our demand of energy is increasing continuously and rapidly with increasing population of the world. Conventional energy sources like coal and petroleum are rapidly decreasing. Saving of energy for future as well as finding alternative energy resources to fulfill our demands in future should be our aim. Solar energy is the best source of energy to fulfill our present and future demands. Sun is the ultimate source of energy. It is easily available anywhere, abundant quantity in nature, available free of cost and its use is free from pollution and it is also inextinguishable resources of energy. Solar energy is available in the form of solar radiation. This radiation needs to be harnessed for making proper use of sunlight. Various types of solar collectors are used to convert solar energy into heat and further it can be transformed into the other forms of energy.*

***Keywords*—** *Heat transfer coefficient, solar intensity, Reynolds number, artificial roughness, Thermal performance.*

I. Introduction

Energy plays key role for economic and social development. Demand for energy has been rising rapidly with increasing population, transportation and industrialization. Due to continuous use of fossil fuels, not only the energy starvation is felt at global level but another serious problem of environment degradation has also been encountered. The rapid decrease in conventional energy sources has made to search for alternative energy resources to meet the existing demand of energy. Of the many alternatives, solar energy is most reliable towards meeting the continuously increasing demand for energy. Solar energy provides a clean and pollution free atmosphere.

Solar air heaters are being used for many applications requiring low to medium grade thermal energy, like space heating and cooling, agricultural drying, timber seasoning, mainly due to their low manufacturing cost, simple design, low operating and maintenance cost. Their use limited because of lower thermal efficiencies primarily as a result of lower convective heat transfer coefficient between the absorber plate and air leading to higher plate temperature and greater thermal losses. Several designs for the enhancement of heat transfer coefficient and improvement of thermal performance of solar air heaters have been proposed and investigated by a number of investigators. Such designs are honeycomb collector, corrugated absorber, V- shape absorber, extended surfaces absorber, double-exposure collector, two pass collector, packing of porous material in air flow channel i.e. packed bed absorbers and use of artificial roughness on the absorber plate. The artificial roughness has been used as an effective means for improvement of thermal performance of solar air heaters. However, this results in increase of friction factor for flowing fluid.



Nomenclature:
Collector area, m^2k
Thermal conductivity of air, W/m K
B solar air heater duct height,
M mass flow rate of air, kg/s
Cp, specific heat of air at constant pressure,
J/kg K, Nusselt number
Ụ, hydraulic diameter of solar air heater duct,
Nua average Nusselt number
E, roughness height, *Nus* Nusselt number for smooth duct

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E+, roughness Reynolds number , hf Heat transfer enhancement factor
E/Ụ, relative roughness height p pitch of roughness element,
F, friction factor P/e relative roughness pitch
F_s, friction factor for smooth duct Re flow Reynolds number
F_r, friction factor for four sided rough duct *To*outlet temperature of air,℃
Average friction factor *Ti* inlet temperature of air,℃
Friction enhancement factor average plate temperature,℃
Friction enhancement factor average air temperature,℃
H convective heat transfer coefficient, W/m^2 K

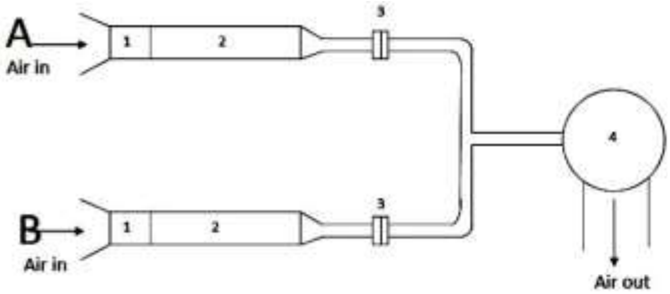

Fig. 1. Schematic diagram for experimental Investigation Proposed.

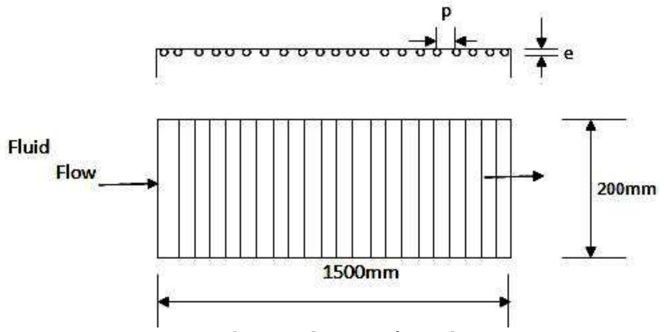

Fig. 2. Schematic diagram of Roughness.

TABLE 1. Relative roughness pitch (p/e) for a maximum value of a heat transfer coefficient for different types of artificial roughness.

Investigators	Roughness Geometry	Value of (p/e) for maximum heat transfer coefficient
Abdul–Malik Ebrahim momin, J.S.Saini, S.C. Solanki (2001)	V shaped rib roughness	10
Rajendra Karwa, S.C.Solanki, J.S.Saini (2000)	Integral chamfered rib	7.9
J.L.Bhagoria, J.S.Saini, S.C. Solanki (2001) M.K. Paswan et al	Transverse wedge shape Wire mess Transverse & logitudial	7.52 9
M.M.Sahu, J.L.Bhagoria (2005)	90˚ broken transverse rib	20
A.R.Jaurker, J.S.Saini (2005)	Rib-grooved	6
Varun, R.P.Saini, S.K.Singal (2007)	Combination of inclined & transverse ribs	8
K.R.Aharwal, B.K.Gandhi, J.S.Saini (2007)	Gap in inclined continuous rib	10
S.V.Krmare, A.N.Tikekar (2008)	Metal rib grits roughness	17.5
Apurba Layek, J.S.Saini,S.C. Solanki (2008)	Transverse chamfered rib-groove	10
S.K.Saini,R.P. Saini (2008)	Arc shaped wire	10
Thakur Sanjay Kumar,Vijay Mittal, N.S. Thakur, Anoop Gautum (2011)	60°inclined continuous discrete rib	12
Sachin Choudhary, Varun, Manish Kumar Chouhan (2012)	Continuous M shaped ribs turbulators	25
A.M.Lanjewar, J.L.Bhagoria, R.M.Sarviya (2012) Pankaj Kumar & M.K.Paswan	W-Shaped Rhombus shape	10 16

TABLE 2. Relative roughness height (e/D) for a maximum value of heat transfer coefficient

Investigators	Roughness Geometry	Value of (e/d) for maximum heat transfer coefficient
Abdul–MalikEbrahim momin, J.S.Saini, S.C. Solanki (2001)	V shaped rib roughness	0.034
Rajendra Karwa, S.C. Solanki, J.S.Saini (2000)	Integral chamfered rib	0.041
J.L.Bhagoria, J.S.Saini,S.C.Solanki (2001)	Transverse wedge shape	0.033
M.M.Sahu, J.L.Bhagoria (2005) M.K.Paswan & S.P.Sharma	90˚ broken tranvers rib Wire mess	0.0338 0.0330
A.R.Jaurker, J.S.Saini (2005)	Rib-grooved	0.0363
Varun, R.P.Saini, S.K.Singal (2007)	Combination of inclined & transverse ribs	0.030
K.R.Aharwal, B.K.Gandhi, J.S.Saini (2007)	Gap in inclined continuous rib	0.0377
S.V.Krmare, A.N.Tikekar (2008)	Metal rib grits roughness	0.044
Apurba Layek, J.S.Saini, S.C. Solanki (2008)	Transverse chamfered rib-groove	0.03
S.K.Saini, R.P. Saini (2008)	Arc shaped wire	0.0422
Sanjay Kumar, Vijay Mittal, N.S. Thakur, Anoop Gautum (2011)	60°inclined continuous discrete rib	0.0498
Sachin Choudhary, Varun, Manish Kumar Chouhan (2012)	Continuous M shaped ribs turbulators	0.0777
A.M.Lanjewar, J.L.Bhagoria, R.M.Sarviya (2012) Pankaj Kumar & M.K.Paswan(2016)	W-Shaped Rhombus Shape	0.018 0.011

TABLE 3. Angle of attack (α) for a maximum value of a heat transfer coefficient for different types of artificial roughness

Investigators	Roughness Geometry	Value of (α) for maximum heat transfer coefficient
Abdul–MalikEbrahim momin, J.S.Saini, S.C. Solanki (2001)	V shaped rib roughness	60°
J.L.Bhagoria, J.S.Saini,S.C. Solanki (2001) M.K.Paswan & S.P. Sharma	Transverse wedge shape Wire mess	90° 90^0
M.M.Sahu, J.L.Bhagoria (2005)	90˚ broken tranverse rib	90°
K.R.Aharwal, B.K.Gandhi, J.S.Saini (2007)	Gap in inclined continuous rib	60°
S.V.Krmare, A.N.Tikekar (2008)	Metal rib grits roughness	60°
Apurba Layek, J.S.Saini, S.C. Solanki (2008)	Transverse chamfered rib-	60°

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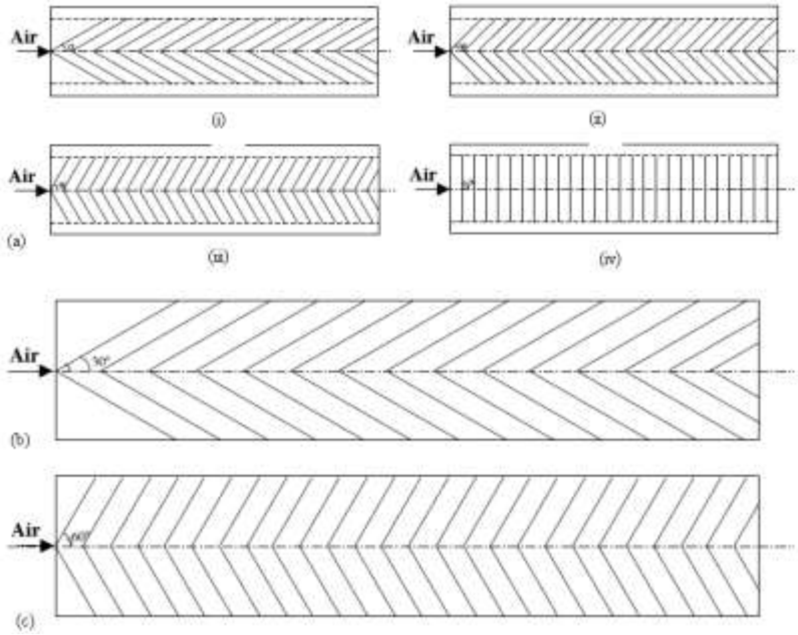
	groove	
S.K.Saini, R.P. Saini (2008)	Arc shaped wire	(α/90 = 0.3333)
Thakur Sanjay Kumar, Vijay Mittal, N.S. Thakur, Anoop Gautum (2011)	60°inclined continuous discrete rib	60°
Sachin Choudhary, Varun, Manish Kumar Chouhan (2012)	Continuous M shaped ribs turbulators	60°
A.M.Lanjewar, J.L.Bhagoria, R.M.Sarviya (2012)	W-Shaped	60°
Pankaj Kumar & M.K.Paswan	Rhombus Shape	90^0



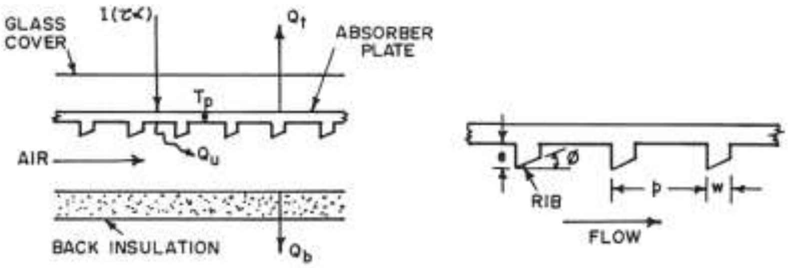


TABLE 4. Correlations developed for heat transfer and friction factor for different roughness geometries

Momin,Saini,Solanki (2001)	V-Shaped rib roughness	Re –2500 –18000, (e/Dh)=0.02-0.034, α =30 –90 ° ,pitch-10.	Nur = 0.067×(Re)0.888×(e/Dh)0.424 ×(α/60°)-0.077×exp[-0.782×(lnα/60°)2] Fr = 6.266×(Re)-0.425×(e/Dh)0.565 ×(α/60°)-0.093×exp[-0.719×(lnα/60°)2]
Karwa,Solanki,Saini (2000)	Integral chamfered rib	Pitch –4.58 –7.09,duct depths 21.8,21.5,16 mm,Re -3750-16350	For 7≤e+ <20 R=1.66e-0.0078φ(W/H)-0.4(p/e)2.695exp [-0.762{ln(p/e)}2](e+)-0.075 WhenW/H>7.75 use W/H=7.75 g= 103.77e-0.006φ(W/H)0.5(p/e)-2.56exp [0.7343{ln(p/e)}2](e+)-0.31 WhenW/H>10 use W/H=10 For 20≤e+≤60 R=1.325e-0.0078φ(W/H)-0.4(p/e)2.695exp [-0.762{ln(p/e)}2] WhenW/H>7.75 use W/H=7.75 g= 32.26e-0.006φ(W/H)0.5(p/e)-2.56exp [0.7343{ln(p/e)}2](e+)0.08
M.K.Paswan & S.P Sharma (2002)	Wire mesh	Pitch- 1.5 -6.25,duct depth-20 mm, Re-3000-20000	
Bhagoria,Saini,Solanki (2001)	Transverse wedge shape	Re –3000-18000 , roughness height 0.075 –0.033 rib	Nur=1.89×10-4(Re)1.21(e/Dh)0.426(p/e)2.94 [exp{-0.71(ln(p/e))2}](φ/10)-0.018 [exp{-1.50(ln(φ/10))2}]
Varun,Saini,Singal	Combination of inclined &	Re-2000-14000,Pitch-5-13mm,W/H-	Nu/Re1.213=0.0006×(p/e)0.0104 and

(2007)	transverse ribs	10	Nu=0.0006×Re1.213×(p/e)0.0104 f/Re-0.3685=1.0858×(p/e)0.0114 and f=1.0858×Re-0.3685×(p/e)0.0104
Karmare&Tikekar (2008)	Metal rib grit roughness	Re-3600-17000,Pitch-15-17.5, e/Dh-0.035-0.044	f=15.55×(Re)-0.26×(e/Dh)0.91×(l/s)-0.27 ×(p/e)-0.51for 3600 < Re < 17000 Nu=2.4×0-3×(Re)1.3×(e/Dh)0.42×(l/s)-0.146 ×(p/e)-0.27for 3600 < Re < 17000
Saini & Saini (2008)	Arc shaped wire	Re-2000-17000,Pitch-10,α/90-0.3333-0.6666,W/H-12	Nu=0.001047Re1.3186(e/d)0.3772 (α/90)-0.1198 f=0.14408Re-0.17103(e/d)0.1765 (α/90)0.1185
Thakur Sanjay Kumar et al. (2011) Pankaj Kumar & M.K.Paswan (2016)	Continuous M shaped ribs turbulators Rhombus shape	Re-3000-22000, Pitch-12.5-75, α-30-60°, e/D-0.037-0.0776 Re-3000-18000,Pitch-18mm,duct depth-20 mm	Nu=3×10-5 (Re)0.947(e/D)0.290(p/e)5.885 (d/w)0.115×exp[-1.237(ln(p/e))2] f=0.014Re-0.23(e/D)0.804(d/w)0.097 (p/e)4.516×exp(-

II. Conclusion

1. This Paper reviews the investigation carried out by various investigators in order to enhance the heat transfer by use of artificial roughness.
2. Use of artificially roughened surfaces with different type of roughness geometries of different shapes, sizes and orientation is found to be the most effective technique to enhance the heat transfer rate with little penalty of friction.
3. Roughness in the form of ribs and wire matrix were mainly suggested by different investigators to achieve better thermal performance. Among all, rib roughness was found the best performer as far as thermal performance is concerned.
4. Correlations developed for heat transfer and friction factor for solar air heater ducts having artificial roughness of different geometries for different investigators are also shown in tabular form. These correlations can be used to predict the thermal efficiency, effective efficiency and then hydraulic performance of artificial roughened.

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