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A Review on Various Enhancement Techniques of Heat Transfer by Using Artificial Roughness in Solar Air Heater

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ABSTRACT

Heat transfer play very important role in thermal engineering. Heat can be transferred by three modes i.e. conduction, convection and radiation. Conduction and convection mode requires medium for heat transfer but in case of radiation no mode medium is required for its working. Convective heat transfer require liquid, air and hot gases for heat transfer, used in various industrial application like drying agriculture products, solar air heater, gas turbines etc. The rate of heat transfer for air is very low due to lower heat transfer coefficient of air. Hot gases and air can also be produced by solar air heaters. This paper describes various artificial roughness techniques used to enhance the heat transfer coefficient of air used in solar air heater. From literature, it has been found that enhanced heat transfer rate is obtained by applying artificial roughness techniques on solar air heater in comparison to convective solar air heater.

Keywords: Heat transfer, artificial roughness, passive and active techniques, relative roughness pitch, relative roughness height.

INTRODUCTION

Energy is required to sustain our life. The energy resources are available on the earth in various forms like Sun light, fossil fuels, hydraulic energy, wind energy, tidal energy, geothermal energy & nuclear energy resources etc. Energy resources may be classified in two ways i.e. conventional energy resources and non-conventional energy resources. Our demand of energy isincreasing continuously and rapidly with increase in the population of world. Conventional energy sources like coal and petroleumare rapidlydepleting. Saving of energy for future as well as finding alternative energy resourcesto fulfill our demands in future should be our aim. Solar energy is the bestsource of energy to fulfill ourpresent and future demand. Sun is the ultimate source of energy.It is easily available anywhere, abundant quantity in nature, available free of cost and its use isfree from pollution in nature. It is inextinguishable resource of energy that provides clean energy.Solar energy is available on the earth 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 energyinto heat and further it can be transformed into the other form of energy

Solar collectors are used in solar air heaters and solar water heaters for heating purpose of air and water respectively. There are various types of solar collectors which have been used for enhancement in thermal efficiency of solar air heaters

(1) Simple flat plate collector
(2) Finned plate collector
(3) Corrugated plate collector
(4) Matrix type collector
(5) Transpiration type collector
(6) Overlapped transparent plate type collector
(7) Single pass solar air heater
(8) Double pass solar air heater
(9) Matrix type solar air heater

Solar Air Heaters

Heating air with solar energy is much cleaner and cheaper than burning fossil fuels.Solar air heater is one of the basic equipment used to convert solar energy into thermal energy. Solar air heater is simple in design and requires low maintenance. Solar air heaters are used to deliver air of lower temperature to increase up to moderate temperatures with the help of absorber plate. Solar air heaters are basically used in drying crops, foods, agriculture industries, drying fruits, commercial domains and buildings in heating climates such as space heating. However, the heat transfer coefficient between flowing air and absorber plate is low;this resultsin lower thermal efficiency of solar air heater. For increasing thermal efficiency of solar air heater,various techniques areused to create artificial surface roughness on the absorber plate.

Concept of Artificial Roughness of Surface for enhancement of heat transfer

Efficiency of flat plate solar air heater is lower because of low convective heat transfer coefficient between absorber plate and flowing air inside the duct. Due to this lower convective heat transfer coefficient results onabsorber plate temperature, leading to higher thermal loss to the environment. It has been found that theseveral investigators have attempted to design an artificially roughness on surface to increase thermal resistance to the formation of laminar sub-layer on the heattransferring surface.Artificial roughness in form of ribs and invarious configurations has been usedon the absorber plate surface to create artificial turbulence near the wall or to break the laminar sub-layer. Artificial roughness in the form of transverse or inclined ribs, V-shaped continuous or broken rib with or without gap, arc shaped wire or dimpled or cavity or compound rib grooves have been observed.

Roughness and Duct Parameters

(a) Relative roughness of pitch (p/e):**-** It is ratio of distance between two consecutive ribs and height of rib.

(b) Relative roughness height (e/D):- It is the ratio of rib height to equivalent diameter of the air duct.

(c) Angle of attack (á):- Angle of attack is defined as the inclination of rib with direction of air flow in the duct of solar air heater.

(d) Aspect ratio:- Aspect ratio is defined as the ratio of duct width to duct height.

(e) Shape of roughness element:- The common shape of roughness in the absorber plate are Square, circular, semi-circular, chamfered, square shaped, arc shaped wire, dimple or cavity, compound rib-grooved, and v-shaped continuous or broken ribs with or without gap, diamond shape with or without gap.

Literature Review of Roughness Geometries

The following papers have been studied and referred in thiswork. Researchers suggested that the various types of artificial geometries are used to increase heat transfer between flowing air and absorber plate.

Gupta *et al*[1] had studied the heat transfer and hydraulic parameters of artificial roughness of plate surface in solar air heater ducts with inclined wires. They were performed with increase in relative roughness height (e/D), the value of Reynolds number (Re) decreased for which effective efficiency maximum. For rough surface maximum enhancement of heat transfer and friction factor was 1.8 and 2.7 respectively corresponding to angle of inclination 60° and 70°. They had also reported that effective efficiency of a roughened solar air heater increaseswith increase in insulation at higher Reynolds number than 10000.

Saini and Saini[2] had reported thatenhancement of heat transfer and frictional characteristics with use of wire mesh roughened absorber plate. In this investigation they considered relative long way length of mesh (L/e) in range of 25-71.87, relative short way length (S/e) range from 15.62-46.87, relative roughness height (e/D) range from 0.12-0.39 and Reynolds number (Re) range from 1900-13,000. They found that the maximum heat transfer is four times incomparison to smooth plate.

Karwa *et al*[3] conducted an experimental investigation of the performance of solar air heaters with chamfered repeated rib-roughness ontheairflow sideoftheabsorberplates.The roughened parametershad been used a relative roughness pitch of4.58-7.09whiletheribchamferanglewas fixedat15°, airflowductdepths range from 21.8-16mm, the relative roughness height range from0.0197-0.0441(for three values), Reynolds number ranges from 3750 to 16350. They observed that the enhancement in thermal efficiency up to 10-40%, Nusselt number up to 50-120% and the increase friction factor up to 80-290.

Momin *et al*[4] done anexperimental investigation on the effect of geometrical parameters of V-shaped ribs surface on heat transfer and fluid flow characteristics. They had used parameters likeReynolds number (Re) range of 2000-17500, relative roughness height (e/D) of roughness 0.02-0.034 and angle of attack ( ) of fluid flow from 30-90° for fixed relative pitch (p/e) of 10. There found that the angle of attack ( ) of 60° in the V-shaped rib increase the value of Nusselt number by 1.4and 2.30 times and friction factor increase by 2.30 to 2.38 over inclined ribs and smooth absorber plate.

Sahu and Bhagoria[5] hadreported that thermal efficiency and heat transfer coefficient in solar air heater using 90° broken transverse ribs on absorber plate. The performance parameters are relative height of rib (e) 1.5mm, pitch (p) 10-30mm, Reynolds number (Re) 3000-12,000, relative roughness height (e/D) 0.338, duct ratio (W/H) is 8. They was found the result for maximum heat transfer coefficient at pitch of about 20mm, heat transfer coefficient and maximum thermal efficiency obtained as 1.25-1.44 times and 83.5 % then the smooth surface duct.

Jaurker *et al*[6] had experimentally investigated the heat transfer and fiction characteristics of artificial roughness by providing rib-grooved geometry on the

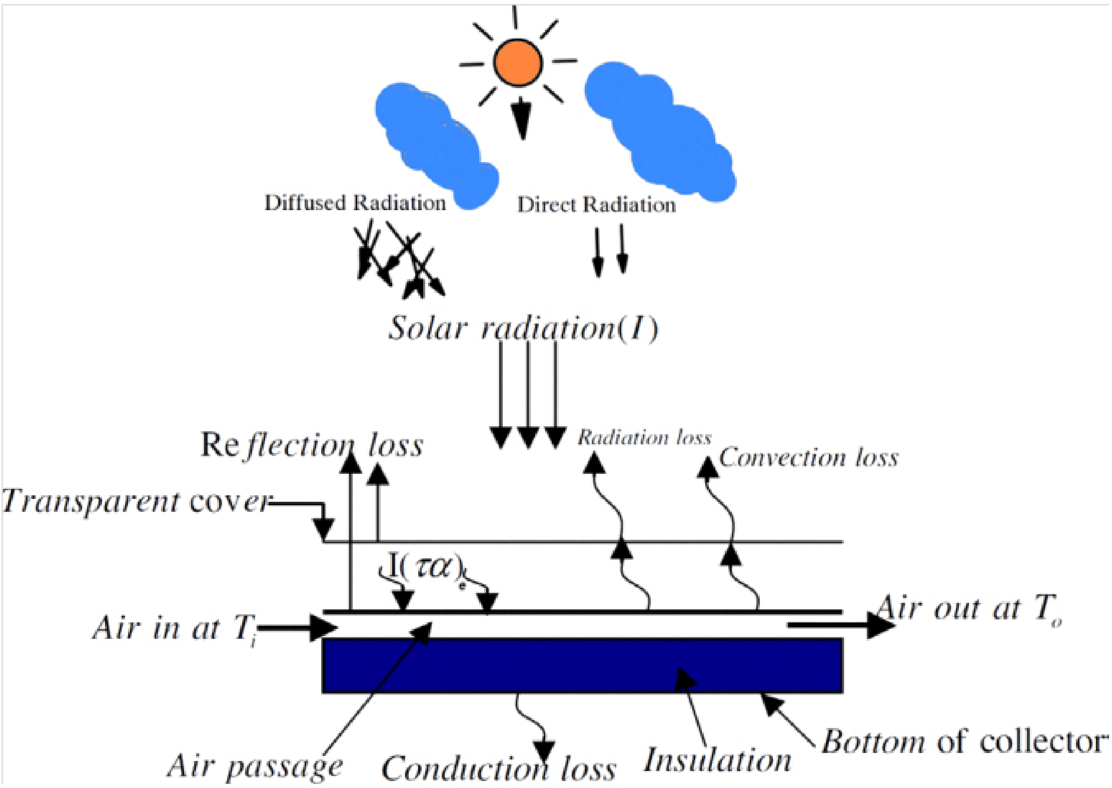

Fig.1: Convective solar air heater[22]

inner surface of absorber plate of solar air heater. They have used parameters likeReynolds number range from 3000 to 21,000, relative roughness height 0.0181–0.0363, relative roughness pitch 4.5–10.0, and groove position to pitch ratio 0.3–0.7. They have found that the optimum condition for heat transfer occurs at a groove position of 0.4, when the relative roughness pitch (p/e) is about 6. It has been also observed that the compared to smooth duct, the pressure of rib grooved artificial roughness increase the Nusselt number up to 2.75 times, while the friction factor raised up to 3.61 times in the range of parameters investigated.

Karmare *et al*[7] had worked on experimental investigation of heat transfer and friction factor correlation for artificially roughened surface of absorber plate with metal grit ribs. Theyused parameters like relative roughness height of grit (e/D) range from 0.035-0.044, relative roughness pitch of grit (P/e) from 12.5-36, relative length of grit (l/s) from 1.72-1, Reynolds number (Re) range from 4000-17,000. The Optimum performance was observed for l/s = 1.72, e/D = 0.044 and P/e = 17.5 for the range of parameters studied. Enhancement in the Nusselt number was found to be 187% and the friction factor by 213 % in comparison with a smooth surface. They were also found that the presence of metal ribs grid on collector surface of the duct increased up to two-fold enhancement in the Nusselt number and three-fold enhancement in the friction factor.

Kumar *et al*[8] has been found that the heat transfer distribution on absorber plate roughened surface with discrete W-shaped ribs in solar air heater. The experiment encompassed Reynolds number (Re) range from3000 to 15,000, rib height (e) values of 0.75 mm and 1 mm, relative roughness height (e/D) 0.0168 and 0.0225 and relative roughness pitch (p/e) of 10 and angle of attack (a) 45°. They were observed that the thermal performanceof roughened W-shaped ribswas compared with that of smooth absorber plate under similar flow conditions and they had reported that the thermal performance of the roughened channel was 1.2–1.8 times the smooth channel for range of parameters.

Saini and verma[9] had experimental worked on the effect of roughness and operating parameters with heat transfer and friction factor in roughened duct provided dimple shaped roughened geometries. In this investigation covered Reynolds number (Re) range from 2000-12,000, relative roughness height (e/D) from 0.018 to 0.037 and relative pitch (p/e) from 8 to 12. They found that the maximum value of Nusselt number corresponds to relative roughness height (e/D) of 0.0379 andrelative pitch (p/e) of 10 and also conclude the minimum value of friction factor for relative roughness height (e/D) of 0.0289 and relative pitch (p/e) of 10.

Varun *et al*[10] had done experimental investigation of solar air heater for heat transfer andfrictional characteristic by using a combination of inclined as well as transverse ribs on the absorber plate. They used parameters like Reynolds number (Re) range from 2000-1400, relative roughness pitch (p/e) 3-8, and relative roughness height (e/D)0.030. It has been found that the maximum heat transfer coefficient and higher thermal efficiency at relative roughness pitch (p/e) at 8.

Aharwal *et al*[11] had experimentally investigated the heat transfer and friction characteristics of solar air heater ducts with integral repeated discrete square ribs on the absorber plate. They used the roughened duct with a width to height ratio (W/H) 5.83, relative roughness gap position (w/D) 0.16 – 0.5, relative gap width (g/e) 0.5-2.0,relative roughness pitch (p/e) 4-10, relative roughness height (e/D) 0.018-0.037, angle of attack () 30-90°, and Reynolds number (Re) range is 3000-18,000. The maximum enhancement is observed at a relative gap position of 0.25 for relative gap width of 1.0, relative roughness pitch of 8.0, angle of attack of 60° and relative roughness height of 0.037.The optimum value for Nusselt number and friction factor have been found 2.83 and 3.60 times respectively in comparison to the smooth ducts.

Pawar *et al*[12] had reported that the heat transfer and friction factor in solar air heater by using artificial roughness in the form of integral wedge shaped rib with and without groove employed on oneof the heated broad wall of the rectangular duct. The wedge angle (θ) was varied from 10° to 25°

while relative roughness pitch (p/e) was kept as 8 and relative roughness height (e/D) was maintained at 0.033. The aspect ratio of the rectangular duct was maintained as 8, Reynolds number range from 3000-20000. The optimum enhancement of heat transfer was observed for the artificial roughness of the wedge angle at 15°. The investigation revealed that Nusselt number increases 1.5-3 times of the smooth duct while the friction factor increases 2-3 times that of the smooth duct in the range of operating parameters.

Ozgan and Esen[13] had worked on inserting an absorber plate made of aluminum cans into double pass channel in to flat plate solar air heater (SAH). These types of collector designed as a proposal to use aluminum material to build absorber plate of solar air heater at suitable cost. Three different absorber plates was designed for experimental study. In the first type (type I), cans had been staggered as zigzag on absorber plate, while in type II they were arranged in order, type III is a flat plate (without cans). The range of air mass flow rate is 0.3 kg/s and 0.5 kg/s are used to experimental study. The optimum collector efficiency and heat transfer coefficient between absorber plate and air was obtained for type I plate at 0.50 kg/s air flow.

Lanjewar *et al*[14] had experimentally investigated the heat transfer and friction factor characteristics of rectangular duct roughened with w-shaped ribs on its inner side on one broad wall arranged at an inclination with respect to flow direction. Range of parameters are used for this studies are Reynolds number (Re) 2300-14000, width to height ratio of duct (W/H) 8.0, relative roughness pitch (p/e) of 10, relative roughness height (e/Dh) 0.018 – 0.03375 and angle of attack of flow () is 30-75°. They have been found that the Values of friction factor and Nusselt number are higher as compared to those for smooth absorber plate.

Saini *et al*[15] had reported that the effect on heat transfer and frictional characteristics of solar air heater with provided artificial roughness discrete V-down ribs on absorber plates. The parameters was used Reynolds number (Re) range of 3000-15000, relative roughness pitch (p/e) range of 4- 12, angle of attack ()range of 30 to 75°, relative gap position (g/e) range of 0.5- 2.0 and relative roughness height (e/Dh) range of 0.015- 0.043. They found that the maximum enhancement in Nusselt number, and friction characteristics is 3.04 and 3.11 times higher than smooth duct and the maximum value of Nusselt number and friction occurs at relative roughness pitch of 8.

Singh *et al*[16] had performed on heat and fluid flow characteristics of rectangular duct having roughened with periodic discrete v-down ribs. Reynolds number (Re) varied from 3000-15,000, with relative gap width (g/e) 0.5-2.0 and relative gap position (d/w) 0.2-0.8. The variation in relative roughness pitch(p/e), angle of attack (), relative roughness height (e/Dh) has been 4-12, 30-75°, 0.015-0.043 respectively. The maximum increase of Nusselt number and friction factor of smooth duct was 3.04 and 3.11 times respectively at the ribs parameters of duct are d/w = 0.65, g/e= 1.0, P/e= 8.0, angle=60° and e/Dh =0.043.

Pawar *et al*[17] had worked on the effect of Nusselt number and friction factor in solar air heater duct with diamond shaped rib roughness on absorber plate. For this investigation used the range of relative pitch (p/e) from 10-25,relative roughness height(e/D) from 0.023-0.028. He had done his work in Reynolds number (Re) ranging from 3000 to 14000.At relative roughness pitch (p/e) 15, they found best roughness pitch ratio and maximum value of Nusseltnumber (Nu) 84.72 at Reynolds number (Re) 14012, and friction factor (Fr) is 0.0194 at Re 3010.

Alam *et al*[18] had experimentally investigated on the effect of circular perforated holes in v-shaped blockages on absorber plate in solar air heater to perform heat transfer with frictional characteristics. He created circular and square holes on V-shaped rib. They investigated on varying relative pitch 4-12, relative blockage height 0.4-1.0, open area ratio is 5-20%, angle of attack () 30-75° and Reynolds number(Re) range from 2000-20,000. Finally results had been found that non circular perforated holes have higher heat transfer in comparisonto circular holes, maximum heat transfer rate and friction factor at 60°.

Tamna *et al*[19] had experimentally worked on channel fitted with multiple V-baffle vortex generators (BVG) provided on the absorber plate. The fluid flow and heat transfer characteristics are presented for Reynolds numbers (Re) ranging from 4000 to 21,000, relative baffle height in terms of blockage ratio (b/H) 0.25, angle of attack () 45°,three different baffle pitch to channel-height ratios (P/H) 0.5-2.0. They found optimum experimental result for that the smaller baffle pitch to channel-height ratio at 0.5 provides the highest heat transfer and friction factor for all V-baffle vortex generators (BVG).

Ray and Jaurker[20] had worked on effect of roughness and flow parameter on heat transfer using multi v-shape rib. The heat transfer rate is increased by providing the artificial width gap geometry. For this study parameters are used i.e. Reynolds number (Re) range from 2000 to 15,000, relative width ratio (W/w) of 3, relative gap distance (Gd/Lv) of 0.24-0.80, relative gap width (g/e) of 0.5-1.5, relative roughness height (e/D) of 0.043, relative roughness pitch (P/e) of 10, angle of attack () of 60°. They were found that the maximum enhancement at a relative gap distance of 0.69 for relative gap width of 1.0, relative roughness pitch of 10, angle of attack of 60°and relative roughness height of 0.043. They have also found that the enhanced the heat transfer coefficient and thermo-hydraulic performance was optimum as compare to inclined rib with gap and multi v-rib without gap.

Pandey *et al*[21] experimental study on the heat transfer and friction factor in absorber plate having roughened surface multiple arc- shaped with gaps. The ranges of Reynolds number (Re) from 2100-21,000, relative roughness height (e/D) ranges from 0.016 to 0.044, relative roughness pitch (p/e) ranges from 4 -16, arc angle (a) values are 30 –75°, relative roughness width (W/w) ranges from 1 to 7, relative gap distance (d/x) values are 0.25–0.85 and relative gap width (g/e) ranges from 0.5 to 2.0.The result of experimental studies is the maximum increment in Nusselt number (Nu) and friction factor (f) is 5.85 and 4.96 times in comparison to the smooth duct.

CONCLUSION

This paper deals with the investigation carried out by various researchers to enhance the heat transfer and friction factor by the use of artificial roughness of different shape, size and others parameters. It can be concluded that there is a considerable enhancement in heat transfer with little penalty of friction on absorber platein the solar air heater. The efficiency of solar air heater can beimprovedby creating artificial roughness on the absorber plate with minimum increase in friction factor. In general, Nusselt number increases with an increase in Reynolds number, and the value of Nusselt number is higher for artificial roughened surface in comparison to smooth surface on the absorber plate. It was also studied that by using double pass solar air heater, the efficiency is increased by 10-15% in comparison to single pass conventional solar air heater.Furthermore, correlations can be used to predict relation between the thermal efficiency, effective efficiency and then hydraulic performance of artificial roughened solar air heater ducts. In this paper tabulated information will be used by researchers to propagate new roughness geometry to performance enhancement of thermo-hydraulic parameters of solar air heaters.

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