ISSN XXXX XXXX © 2017 IJESC

Research Article Volume 7 Issue No.12

Studies on Shapes of Turbulators on the Absorber Plate of Solar Air Heater System

Shashank D. Bhujade[1], Dr. R. S. Shelke[2]
PG Student[1], Professor[2]
Department of Mechanical Engineering
G. H. Raisoni College of Engineering, Nagpur, Maharashtra, India

Abstract:
The solar air collector is one of the most important parts of solar air heater system which is responsible for collecting solar energy including on it and finally transforming that energy into the thermal energy. It also plays an important role of exchange by selling the energy captured the coolent (air) flowing through them. The use of them is space heating, drying, seasoning of timber etc. The design of any collector is based on required efficiency, their destination and mainly on cost of instaullation .Several models were constructed and studied by different researchers to identify the parameter that characterize them. In this paper, different shapes turbulator on absorber plate of solar air heating system studied by different investigators are reviewed. The solar collectors with different shapes of turbulators on the basis of cost factor, efficiency parameter, heat transfer , pressure drop, types of collector ,heat transfer rate and Reynolds number are studied .In this paper, the influence of above parameter on physical and geometrical characteristics of air stream flowing inside collector with different shapes of turbulators are also reviewed.

Keyword: Absorber, Different types of turbulator, solar collector, Turbulent flow.

1. INTRODUCTION:

Because of increase in energy demand and consumption due to increase in economic growth and population growth, energy efficiency and energy saving are of great concern. Solar air heater particularly heat exchanger are devices which converts solar energy into thermal energy at low cost and easily because of development in technologies. Solar air heater are devices of solar energy system which absorb solar radiation and convert it into thermal energy at absorber surface and finally transformed the energy to the fluid flowing inside the solar collector. Solar air heaters can be used for the applications like drying, curing of agricultural products, space heating for human comfort, curing of industrial products, seasoning of timber etc. (generally low and moderate level application).As far as the application for heating of air to maintain a comfortable environment is concerned, solar air heater is most logical choice. Solar air heater is system used for producing hot air with help of sun without any use of conventional fuels like LPG, coal, diesel, electricity etc. Solar air heaters (SAH) are generally used to convert solar energy into thermal energy. The solar air heater generally composed of absorber plate, glazing and properly insulated box. SAH generally classified on basis of air passed as,

- Air flowing between glazing and absorber plate.
- Air flowing between absorber surface and back plate.
- Air flowing between above and below absorber plate.

Actually, it is found that thermal efficiency of simple solar air collector is very poor because of thermos-physical property of air and low convective heat transfer coefficient of air and hence formation of viscous sub-layer appears on absorber which resist to heat transfer rate. Hence, in order to improve efficiency of solar collector, many techniques are available which may be active or passive methods. One may use vortex generator, which consist of turbulators, ribs which acts like disturbance promotor and increases fluid mixing and interrupt development of thermal boundry layer, leads to enhancement of thermal heat transfer. The heat transfer enhancement is done by

- Increasing the heat transfer area with use of extended surfaces or turbulators.
- Increasing heat transfer coefficient.

Solar collector:
Solar collector for heating of air may be classified by their distribution of air paths or by material type such as glazed or unglazed.

- In through pass configuration, air passes through one side of absorber from perforated or fibrous type material and heated because of conductive property of material. This collector offers more surface area which enables high convective heat transfer rate but greater fan power required for significant pressure drop.
- In back, front and combination of both type collector, air passed through back, front and both combination side of absorber to be heated from return to supply ducting headers. Air passing through both side of duct offers greater surface area for convective heat transfer but there is issue of fouling which reduces efficiency.
- Unglazed air collector is also known as transpired solar collector which is generally used to heat ambient air in process and commercial, agricultural application. Unglazed air collector consist absorber surface without any glass or glazing cover over top.
- Glazed solar collector also called as recirculating types generally used for space heating application.

Different shapes of turbulators on absorber surface:

- Flat ribs on absorber surface: cross-section of rib mainly affects the geometry of separated region and level of disturbance in the flow. It is found that friction factor is more for rectangular or square circular cross-section in comparison to that of circular cross-section ribs. This causes increment in skin friction, results in decreasing the friction factor. The size of separated region affects the heat transfer adversely. Another possible factor, decrease reduction in heat transfer surface area causes decrease in Nusselt number.

- **Inclined ribs on absorber plate :**

The inclined rib with respect to flow creates secondary flow along the span that causes span wise variation of heat transfer coefficient. The vortices move along the rib to subsequently join the main stream i.e. the fluid enters at the leading end of the rib. The moving vortices bring the cooler channel fluid in contact with leading end, raising heat transfer rate while the trailing end heat transfer is relatively low. This results in strong span wise variation of heat transfer.

- **V-shaped turbulator on absorber surface:**

The possibility of further enhancing the wall heat transfer by the use of V-shaped ribs is based on the observation of the creation of secondary flow cell due to angling of the rib resulting in a region of higher heat transfer near the leading end. By splitting the long angled rib into a V-shape to form two leading ends and a single trailing end, a much larger (about double) region of high heat transfer is produced. It is infect the formation of two secondary flows cells instead of one as in the case of transverse rib that results in higher overall heat transfer in the case of V-shaped ribs.

- **Discretized V-shaped turbulator on absorber surface:**

The v-shaped ribs along with staggered rib pieces in between further increase the number and area of heat transfer regions. Additional rib parameters related to the size and positioning of rib pieces (length ratio, segment ratio and staggering ratio) with respect to main rib produce complex interaction of secondary flow.

- **Chamfered rib on absorber surface:**

Chamfering of the rib decreases the reattachment length by deflecting the flow and to reattach it nearer to the rib. The decrease in reattachment length permits to organize the ribs more closely. Chamfering of the rib also increases the shedding of vortices generated at the rib top that results in increase turbulence. For higher chamfer angle flow separates from the rib top surface and generates boundary layer, which decreases the heat transfer. The friction factor increases due to the creation of vortices.

2. LITERATURE SURVEY:

2.1 Heat transfer and friction factor:

- Momin et.al [1] investigates effect of V-shaped rib on heat transfer and friction factor. The V-shaped rib used by Momin shown in fig.1 .During this experimentation, he found that Reynolds number ranges from 2500-18000,relative roughness height was 0.020-0.034 and angle of attack ranges from 30-90°.For this geometry, he observed that with increase in Nusselt number ,increase in Reynolds number is lower than increase in friction factor. Maximum enhancement in heat transfer and friction factor has been found 2.3 to 2.83 times more than smooth surface for angle of attack of 60°.He also found that for V-shaped rib, heat transfer is better and also better performance as compared to that of inclined rib.

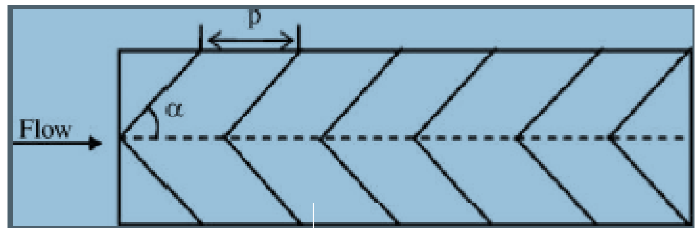

Figure.1. V-shaped rib

- Amin Ebrahimi et.al [2] done investigation on thermo-hydraulic performance of flat plate collector with pyramidal protrusion. The pyramidal protrusion used by Amin .For the experimentation; he uses Reynolds number in range of 135 to 1430.He studied the effect of turbulator size, shape and protrusion arrangement on the performance of flat plate channel. He observed that with pyramidal protrusion, heat transfer enhanced by 277.9% and amplify pressure drop by 179.4% with respect to plane channel. He also observed that overall effective efficiency increased by 12-169.4% as compared to plane channel. He again investigates that dividing of domain into many zones cause better control on grit size. He found maximum heat transfer when Reynolds number was 1430 and angle of attack was 45°.
- Saini and Saini [3] carried out experimentation in order to enhance heat transfer .For this purpose, he provided artificial roughness in the form of parallel wire of arc shape on absorber plate shown in fig.2. He studied effect of Nusselt number and Reynold number ranging from 2000 to 17000, relative roughness height 0.0215-0.0422 and arc angle 0.333-0.666 on artificial roughness. He observed that providence of arc shaped geometry on absorber cause increase in heat transfer. He found increase in Nusselt number by 3.80 as compared to smooth surface while friction factor by 1.75 times.

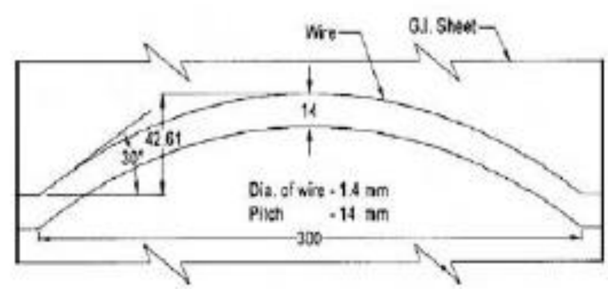

Figure.2 Arc shaped rib.

- J.L.Bhagoria et.al [4] works on rectangular solar air duct with transverse wedge shaped rib roughness. Bhagoria's transverse wedge shaped rib is shown in fig.3. During experimentation, he observed Reynolds number in range of 3000-18000,relative roughness height in range of 0.015-0.033 and rib wedge angle 8,10,12 and 15°.During experimentation, he found that maximum heat transfer occur when roughness pitch is of 7.57. Heat transfer enhancement was found at wedge angle of

10° and friction factor was increased to 5.3 as compared to smooth duct.

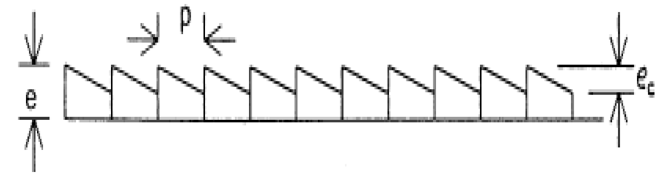

Figure.3. Transverse wedge shaped rib.

- Prasad and Saini [5] investigate the effect of artificial roughness on heat transfer and friction factor on solar air heater. He uses protrusion wire on absorber plate which drastically increases the turbulence and hence enhancement in heat transfer rate. He observed that, for Reynold number 5000, relative roughness height 0.020-0.027 and nusselt number 328.6 then maximum heat transfer can obtained. The rate of increase of relative roughness height is 0.027 – 0.033. He also observed that, small diameter of wire protrusion cause increase in heat transfer (Mostly doubles).

2.2 Efficiency:

- Chii-Dong Ho et.al [6] investigates that solar air heater with wire mesh packed gives good heat transfer rate, friction factor and efficiency. He made comparison between single pass, double pass and recycling wire mesh double pass operations. This arrangement creates turbulence which enhances the heat transfer coefficient in great extend which results in increase in efficiency. He also observed that collector with wire meshed packed double pass operation is higher than remaining other configuration. He also observed that increase in mass flow rate and recycle ratio improves collector performance. The solar air heater with wire packed mesh arrangement shown in fig.4. Double pass arrangement with and without wire mesh configuration were made and performance of them was investigated. He found that, wire mesh attachment on double pass arrangement is technically and economically feasible. This type of design causes division of air flowing into sub-channel and inserting wire mesh into lower sub-channel. He observed that increase in recycle ratio and mass flow rate due to velocity enhancement cause increase in efficiency.

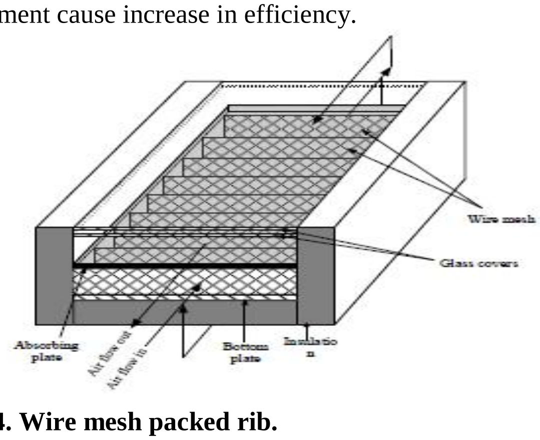

Figure.4. Wire mesh packed rib.

- J.C.Han et.al [7] investigates performance of heat transfer ducts with V-shaped broken ribs. Hans turbulator with V-shaped brocken ribs shown in fig.5. He observed that, for the Reynolds number 15000- 90000, relative roughness height 0.0625 and angle of attack 45°, maximum effective efficiency is observed. Heat transfer rate increases by 2.5 – 4 times that of continuous rib or V-shaped continuous rib. For given Reynolds number, the V-shaped rib at 60° is having higher heat transfer as compared to other. For such ribs, he observed that Nusselt number ratio decreases to minimum and increase to maximum value downstream due to favorable secondary flow induced by rib.

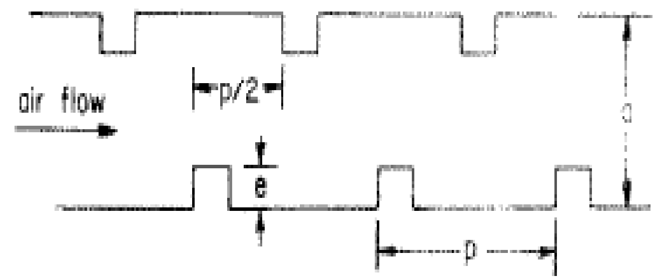

Figure.5. Stragged rib

- Chii-Dong Ho et.al [8] investigates performance of recycling double pass V-corrugated solar air collectors. In this arrangement, air flowing over and under this geometry, which enhances the convective heat transfer coefficient and finally increases thermal efficiency. This V-corrugated absorber divide air flowing conduit into double sub-channel. He observed that increasing mass flow rate and recycling ratio increases collector efficiency in great extent because of increasing convective heat transfer coefficient and heat transfer area. He observed that efficiency obtained with recycling double pass V-corrugated solar air collector is better than that of smooth surface.
- M.K.Mittal et.al [9] uses artificial roughness on solar absorber plate and enhances the heat transfer rate. He gave comparative comparison of different roughness geometries on the absorber plate. Roughness geometry and by Mortal. During experimentation, Reynolds number ranges from 2000- 15000. He observed that effective efficiency increases with increase in Reynolds number and their by starts decreasing because of mechanical power required for reduction in frictional forces of duct. He also observed that when Reynolds number is less than 12000, better effective efficiency is obtained. He also observed that in lower range of Reynolds number, efficiency increases by 2.5% for expanded metal mesh geometry and 0.8% for inclined rib. With using relations of heat transfer and friction factor, he calculated effective efficiency in range. Solar heater with inclined ribs as turbulator has found more efficiency in higher range of Reynolds number. In this study, he found that expanded metal mesh have suitable roughness in lower range of Reynolds number.

2.3 Comparism of roughness geometry:

- Anil Kumar [10] investigates that artificial roughness on solar absorber surface creates turbulence, which brecks laminar sub-layer and finally enhances heat transfer coefficient. In his work, he creates artificial roughness in the form of V-shaped, Multi V-shaped ribs and Multi V-shaped ribs with gaps and he analyzed all this geometries with CFD. He investigates the effect of turbulator geometries on heat transfer and friction factor. He analyzed different turbulator geometries and compared the results with Dittus-Boelter empirical relationship for smooth surface. He noted that maximum heat transfer found when relative gap width is 1, aspect ratio is 12, relative roughness is 10 and angle of attach is 60˚. With different roughness geometries on the solar absorber plate, he has drawn following different conclusions

1. He found enhancement in heat transfer coefficient with different roughness geometries as compared to that of plane flat surface.
2. In case of Multi V-shaped ribs with gap, He found maximum heat transfer and friction factor.
3. During experimentation, he found Renormalization K-epsilon model, results are very good.

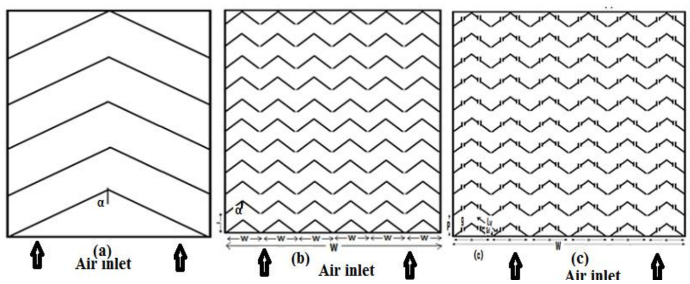

Figure. 6 (a) V-shaped rib (b) Multi v-shaped rib (c) Multi v-shaped with gap rib.

- Suleyman karsli [11] analyzed the performance of four types of solar air heating system: collector provided with finned shaped turbulator provided at an angle of 75˚, a collector provided with 70˚ finned turbulator, collector with tube and a base collector. He find out the first and second laws of efficiency and compared among all of them. He found that rise in efficiency mainly depends on incident solar radiation and design of solar collector. The first law of efficiency changed between 26% and 80% for first collector, between 26% and 42% for second collector, between 70% and 60% for third collector and for fourth collector, between 26% and 64%.The second law efficiency changes from 0.27 to 0.64. The highest efficiency was achieved by finned collector with angle of 75˚ whereas lowest value for base collector. He observed that introduction of promotors, turbulators, fins and obstracles in absorber plate increases the heat transfer rate and increases the output temperature of air leaving the collector at outlet. He observed that the maximum efficiency observed in multi V-shaped rib with gap as compared to other geometries. He also observed that absorber temperature remains higher than collector with obstracles, cause thermal heat loss by radiation hence cause reduction in efficiency. He found that creation of turbulence cause higher rate of heat transfer, which lower absorber temperature and reduces thermal heat loss.

- Han et.al [12] investigates on heat transfer and friction factor for roughened rib surface. He investigates effect of angle of attack, rib size, rib shape on friction factor and heat transfer. In this geometry, inner surface is rough and outer surface is smooth. He observed that, when angle is 40°, heat transfer rate reduce by 20% .For Ø=55°, heat transfer rate reduces by 8%. He observed that, when pitch to height ratio of rib is 10 then Stanton number and friction factor found to be maximum. He also observed that rib roughness with 45° as attack angle gives high heat transfer rate for same frictional power as compared to rib with 90°, flow attack angle.

2.4 Performance parameters:

- Sunil Chamoli [13] studied perforated V down baffle projections using Taguchi experiment method. Chamoli studied rectangular channel with V down perforated baffle attachment to one of the wall of channel with different roughness parameters. He investigates different performance parameters like Reynolds number, area ratio, relative roughness pitch and relative roughness height. Nusselt number and friction factor are considered as impotent parameters in Taguchi experimental design method. He found that, maximum heat transfer can be found when relative roughness pitch is 2, relative roughness height is 0.4 and Reynolds number is 18600. The analysis of Taguchi experiment is done with goal of optimization process for maximum Nusselt number and minimum friction factor. He concluded that other experiment takes too much time but in case of Taguchi method, very limited number of experiments and short span of time is required.

- Vipin Gawande et.al [14] analysed the thermal performance of thermal system. He developed an algorithm in MATLAB. For solar air heater with rib at an angle of 20˚.He found that solar air heater with roughened absorber surface have higher thermal efficiency as compared to smooth surface. He also obsereved that with increase in mass flow rate, heat transfer rate increases. The number of glazing on collector surface and with of the duct also improves the effective efficiency of collector. Heat transfer coefficient increases with increase in velocity of flowing air, which reduces useful heat gain. Author studies the effect of heat flux, number of glazing, with of duct, velocity of air and its effects. He concluded that square rib with an angle of 20˚ was found with good thermo-physical properties. Increase in mass flow rate increases effective efficiency of collector. Higher value of effective efficiency obtained with increase in number of glazing and higher value of duct width. He also found for square rib with 20˚ angle have minimum pumping power and maximum heat transfer coefficient.

- Varun et.al [15] adapted different techniques to increase the performance of solar heater .He uses fins, Projections, roughness geometries. He founded different system and operating parameters in order to get maximum thermal benefits. He uses genetic algorithm in order to find out emissivity of plate. Tilt angle and glazing over solar collector. It is found that thermal efficiency of solar air heater without any turbulater is lower because of lower heat transfer capability. For this varun studied optimum system and operating parameters so that system operates at highest capabilities. He observed that increase in number of glazing cover on collector increases thermal performance of collector but increases cost of the system. He also observed that increase in Reynolds number increase the thermal performance of system. It is found that increase in irradiance on solar collector plate cause increase in mean temperature of plate cause increase in top loss coefficient of solar flat plate collector which indirectly decreases the thermal performance of solar air heater.
- A.Boulemtafes-Boukadoum et.al [16] makes CFD based analysis of heat transfer enhancement in solar heater provided with transverse rectangular rib. In transverse rib, He observed that growth in friction factor is almost double of heat transfer. He also claimed that generation of artificial roughness is not easy and economical task for large scale production. He found that with above geometry , heat transfer enhancement by 1.92 times that of smooth channel and pressure loss by 1 to 21.5 times of smooth channel.

Table.1. Comparative comparison between roughness parameter:

Sr. No.	Author	Roughness geometry	Observation	Remark
1	Momin	V-shaped rib	Re=2500-18000, α=45°, (P/E)=0.020-0.034.	V-shaped rib has max. Heat transfer as compared to inclined rib.
2	Amin Ebrahimi	Pyramidal Protrusion	Re=1430, α=45°.	Heat transfer enhanced by 277.9% and effective efficiency increased by 12-169.4%.
3	Saini and Saini	Arc shape rib	Re=2000-17000, α=60-90°, (P/E)=0.0215-0.0422 .	Increase in Nusselt umber by 3.80 as compared to smooth surface while friction factor by 1.75 times.
4	Bhagoria	Wedge shaped rib	Re=3000-18000, α=8, 10, 12 and 15°, (P/E) =of 0.015-0.033.	Heat transfer enhancement found at wedge angle of 10° and friction factor was increased to 5.3.
5	Prasad and Saini	Small diameter transverse	Re=5000, Nu=328.6, (P/E)= 0.020-0.027.	Small diameter of wire protrusion cause increase in heat transfer (Mostly doubles).
6	Chii-Dong ho	Wire mesh	Re=2000-16000, α=45°, (P/E)=0.027-0.033.	Increase in mass flow rate and recycle ratio improves collector performance.
7	J.C.Han	V-shaped broken ribs	Re=15000-90000, α=45°, (P/E)=0.0625.	Heat transfer rate increases by 2.5 – 4 times that of continuous rib or V-shaped continuous rib.
8	Chii-Dong ho	Recycling double pass V-corrugated	Re=1500-9000.	Efficiency obtained with this arrangement is better than that of smooth surface.
9	M.K.Mittal	Comparison of different roughness geometries	Re=2000-15000.	Efficiency increases by 2.5% for expanded metal mesh geometry and 0.8% for inclined rib.
10	Anil Kumar	V-shaped, Multi V-shaped ribs and Multi V-shaped ribs with gaps	Re=2000-20000, α=60°, (g/e)=1,(P/e)=10.	Maximum heat transfer and friction factor found in Multi V-shaped ribs.
11	Suleyman Karsli	Finned shaped turbulator at an angle of 75˚,70˚, collector with tube	Second law efficiency changes from 0.27 to 0.64	Maximum efficiency observed in multi V-shaped rib creation of turbulence cause higher rate of heat transfer.
12	Han	Roughened rib surface	α=40-55°, (P/e) =10.	Rib roughness with 45° as attack angle gives high heat transfer rate for same frictional power as compared to rib with 90°.
13	Sunil Chamoli	V down baffle projections	Re=18600, (P/e)=4, (P/E) =0.2.	Taguchi experiment gives maximum Nusselt number and minimum friction factor.
14	Vipin Gawande	Rib at an angle of 20˚.	α=20°.	Higher effective efficiency obtained with increase in number of glazing and increase in duct width. Given rib have minimum pumping power and maximum heat transfer coefficient.
15	Varun	Inclined rib	Re=2000-20000.	Increase in irradiance on solar collector plate cause increase in mean temperature of plate cause increase in top loss coefficient of solar flat plate collector.
16	A. Boulemtafes	Transverse rectangular rib	e=3.4,aspect ratio=7.5,p=34mm.	Heat transfer enhancement by 1.92 times that of smooth channel and pressure loss by 1 to 21.5 times of smooth channel.

Table 1 shows V-shaped rib used by Momin [1] enhances heat transfer rate in comparison with inclined rib. The pyramidal protrusion used by Amin [2] increases heat transfer by 277.9%.

Anil kumar [10] provides comparative comparison between various geometry and found that Multi V-shaped rib have maximum heat transfer and friction factor. Suleyman Karsli [11] also compare different shapes and found same result as observed in Anil Kumar [10].Hans [12] used roughened rib surface and found that rib with angle of attack 45° have high heat transfer rate. For centuries people of various nations have been preserving dates, figs, apricots, grapes, bananas, pineapples, other fruits, herbs, cassava, yams, potatoes, corn, peas, onions, garlic, carrots, peppers, milk, coffee, meat, and fish by solar drying . But, drying is also beneficial for hay, copra (kernel of the coconut), tea and other income producing non-food crops. It is worth noting that until around the end of the 18th century when canning was developed, dehydration was virtually the only method of food preservation. Now a day above mentioned all geometries are used for food preservation, drying products which require comparatively less time for drying as compared to olden techniques.

3. CONCLUSION:

In present study, a review of different shapes of turbulator on absorber plate of solar air heater system is carried out and various performance parameters of solar air heater system for roughened elements like ribs, protrusion, turbulators, obstracles etc. are studied and are compared with different geometries in order to find out best roughness geometry of turbulator. From above review, following important conclusions are drawn

- Use of different types of turbulators on artificially roughened surface of different geometries having different shapes, size and arrangement found most effective method to increase heat transfer rate with little penalty of friction.
- For getting better thermal performance, most of the investigators use turbulators in the form of ribs and wire matrix. From all, ribs as a turbulator was found most effective thermal performance is concerned.
- In artificially roughened solar air heater, there is lot of scope of use of flow visualization technique in order to analyse flow and heat transfer enhancement process.
- Thermo-hydraulic performance of pyramidal protrusion as a turbulator found to be better in comparison to other roughness element geometries for Reynolds number range between 135 to 1430.
- For further improvement, investigation on twisted tape turbulator in a circular tube arrangement found maximum heat transfer as compared to other shapes of turbulator and hence for further improvement, exhaustive study must be carried out above mentioned shape of turbulator.i.e on twisted tape turbulator in a circular tube.

4. REFERENCES:

[1]. MominA.M.E ,Saini.J.S , Solanki.S.C, Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate , International Journal Heat Mass Transfer 45(2002) 3383-96.

[2]. Amin Ebrahimi, Benyamin Naranjanir, An investigation on thermo-hydraulic performance of a flat-plate channel with pyramidal protrusions, Applied Thermal Engineering 186 (2016) 316-324.

[3]. Saini RP, Saini JS. Heat transfer and friction factor correlations for artificially roughened ducts with expanded metal mesh as roughened element. Int J Heat Mass Transfer 1997; 40(4):973–86.

[4]. Bhagoria JL, Saini JS, Solanki SC. Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. Renewable Energy 25(2002) 341–69.

[5]. Prasad BN, Saini JS. Effect of artificial roughness on heat transfer and friction factor in a solar air heater. Solar Energy 41(1988) 555–60.

[6]. Chii-Dong Ho, Ching-Fang Hsiao ,Hsuan Chang , Yi- En Tien, Investigation of device performance for recycling double-pass V-corrugated solar air collector, Energy Procedia 105 (2017) 28-34.

[7]. Han JC, Zhang YM. High performance heat transfer ducts with parallel, broken and V-shaped broken ribs. Int J Heat Mass Transfer1992; 35(2):513–23.

[8]. Chii-Dong Ho,Hsuan Chang , Chun-Sheng Lin , Chun-Chief Chao. Analytical and experimental studies of wire mesh packed double-pass solar air heaters under recycling operation. Energy Procedia 75 (2015) 403-409.

[9]. M.K.Mittal, R.P.Saini, S.K.Singal, Effective efficiency of solar air heater having different types of roughness elements on absorber plate, Energy 32 (5) (2007) 739-745.

[10]. Anil kumar, Analysis of heat transfer and fluid flow in different shaped roughness elements on the absorber plate solar air heater duct, Energy procedia 57 (2014) 2102-2111.

[11]. Suleyman Karsli., Performance analysis of new-design solar air collectors for drying applications, Ataturk University, Pasinler Meslek YuksekOkulu, Pasinler, Erzurum 25300, Turkey, Renewable Energy 32(2007) 1645-1660.

[12]. Hans.V.S ,Saini.R.P , Saini. J.S, Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs, Solar Energy, 84, 2010, pp.898-911.

[13]. Sunil Chamoli , A Taguchi approach for optimization of flow and geometrical parameters in a rectangular channel roughened with V down perforated baffles , Songklanakarian J. Sci.Technol. 36(2) (2014) 201-208.

[14]. Vipin B. Gawande, A.S.Dhoble, D.B.Zodpe, Sunil Chamoli, Analytical approach for evaluation of thermos hydraulic performance of roughened solar air heater , J.Sci.Technol. 8 (2016) 19-31.

[15]. Varun Naveen Sharma, I.K.Bhat,D.Groover , Optimization of smooth flat plate solar air heater using stochastic iterative perturbation technique , Solar Energy 85 (9) (2011) 2331-2337.

[16]. Boulemtafes .A. CFD based analysis of heat transfer enhancement in solar air heater provided with transverse rectangular ribs. Renewable Energy 50(2014) 761-772.

[17]. Gupta.D, Solanki.S.C , Saini.J.S, Heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plates, Solar Energy (51), 1993, pp.31?37.

[18]. Chaube.A, Sahoo.P.K, Solanki.S.C, Analysis of heat transfer augmentation and flow characteristics of a solar air heater, Renew able Energy (31), 2006, pp.317?331.

[19]. Karmare.S.V, Tikekar.A.N, Analysis of fluid flow and heat transfer in a grit roughened surface solar air heater using CFD, Solar Energy, 84(2010), pp. 409-417.

[20]. Kumar.A , Saini.R.P , Saini.J.S, Experimental investigation on heat transfer and fluid flow characteristics of air flow in a rectangular duct with Multi V-shaped rib with gap roughness on the heated plate, Solar Energy, 86 (2012), pp.1733-1749.