A REVIEW OF SPSAH AND DPSAH CHARACTERISTICS BY VARIATION OF FLUID PROFILE IN THE DUCT

Abstract: The thermal performance of solar air heaters can be enhanced by increasing the rate of heat transfer. The thermal performance of DPSAH is higher than that of SPSAH based on the study of various researchers. Many researchers have studied the performance analysis of solar air heaters with various heat transfer enhancement techniques like using fins, corrugated absorber plate, packed bed, generating turbulence to the flow. By using ribs of different geometrical shapes and sizes attached to the absorber plate turbulence increases which in turn increases the thermal and thermo-hydraulic performances of the solar air heater. The paper presents the study of the research carried on various processes used to increase turbulence and so thermal performance of SPSAH and DPSAH.

Keywords: SPSAH, DPSAH, Nusselt Number, Reynolds Number, Prandtl Number, Thermal Efficiency, Thermo-Hydraulic Efficiency, Roughness pitch.

Table 1: Nomenclature

| Notation | Description                  | Notation | Description                  |
|----------|------------------------------|----------|------------------------------|
| SPSAH    | Single Pass Solar Air Heater | DPSAH    | Double Pass Solar Air Heater  |
| A_c      | Absorber(Collector) plate area (m²) | A_o | Orifice meter throat area (m²) |
| D_h      | Hydraulic Diameter (m)       | e        | Roughness element height (mm) |
| f        | Friction factor              | H        | Height of duct (m)            |
| HT       | Heat Transfer                | p        | Pitch                        |
| Nu       | Nusselt Number               | Nu_max   | Maximum Nusselt Number        |
| Pr       | Prandtl Number               | Re       | Reynolds Number               |
| W        | Width of duct (m)            | e/D_h    | Relative roughness height    |
| p/e      | Relative Roughness pitch     | W/H      | Aspect Ratio                 |
| α        | Angle of attack              | η        | Thermal efficiency           |
| η_max    | Maximum efficiency           | η_th     | Thermo-hydraulic efficiency  |

1) Introduction:

Energy is available in various forms and plays a significant role in the technological advancements as without energy the world may halt. The amount of energy consumed in the past 50 years has been growing in an exponential rate and the fossil fuels are at the brink of exhaustion. This has increased the interest in search and utilisation of renewable energy sources. Renewable energy sources like solar energy, wind have been part of humans from pre-historic age but there vast applications came into use only in 1900’s. The demand for
heating and cooling systems based on renewable energy sources has been rising recently and solar energy is one of them which possess high efficacy if utilised. Solar energy does not impose any negative effects on environment and can be easily harnessed but till now we cannot attain the complete absorption. It is generally used for various applications like heating, cooling, power generation, etc.

Solar heaters are varied based on the fluid used here air is considered as it is freely available in the atmosphere. Solar air heater is commonly used for heating where energy in the form of heat from sun is absorbed on a collector and a fluid here air flows over the collector absorbing the heat and transferring to the required application. Solar air heaters can be classified into two types on the basis of number of passes on the absorber plate like single pass and double pass solar air heater.

The conventional solar heater has low thermal efficiency as convective heat transfer coefficient between absorber plate and air is low. For increasing the performance of solar air heater many views were presented by the investigators like increasing the absorber surface area which increases the space requirement, increasing surface roughness or imperfections on the absorber plate, use of fins, corrugated absorber plate, etc. Generating turbulence is the best possible way for increasing the performance of solar air heater and it is obtained by increasing surface roughness, creating obstacles to the flow. An artificial roughness increases the turbulence by breaking the laminar sublayer of the fluid flow and so enhancing the heat transfer capacity. From the literature it was observed that DPSAH has more efficiency than SPSAH. This paper presents the various observations of the researchers on SPSAH and DPSAH for enhancement in thermal performance.

2) Review on SPSAH:

A SPSAH is which air passes only once on the collector plate collecting heat.

Shalini Rai et al.[1] Has done simulation on absorber plate having offset fins with parameters varying in fin spacing with respect to Reynolds number.

They concluded that Absorber efficiency decreases with raise in mass flow rate and Collector efficiency increase with low fin spacing and fin height.

Fin Spacing 1 cm to 5 cm
Mass flow rate 50kg/h
Solar insolation 950w/m²

Anil Kumar [2] has done his numerical analysis on absorber plate with ‘V’ shaped ribs, Multi ‘V’ shaped ribs and Discrete Multi ‘V’ shaped ribs.

Parameters considered were
V-shaped rib P/e =10, θ=60°, e/D=0.043
Multi V-shaped rib P/e =10, θ=60°, e/D=0.043, W/w=6
Multi v-shaped ribs with gap $P/e = 10$, $\alpha = 60^\circ$, $c/D = 0.043$, $W/w = 6$, $g/e = 1.0$, $Gd/Lv = 0.69$ 

He concluded that 

Heat transfer enhanced by 1.7, 4.7, 5.6 times for V shaped ribs, Multi V shaped ribs, Multi V shaped ribs with gaps in comparison to smooth plate.

Brij Bhushan and Ranjit Singh [3] has done analysis on absorber plate with protrusions. The following parameters have been considered 

| Solar insolation | 600 to 1000w/m² |
|------------------|-----------------|
| Relative long way length ($L/e$) | 25.0–37.5 |
| Relative short way length ($S/e$) | 18.75–37.5 |
| Relative print diameter ($d/D$) | 0.147–0.367 |

They has attained a conclusion that Thermal efficiency has 2.3 times enhancement and Effective efficiency has 2.2 folds increase compared to smooth plate.

Gawande et al.[4] Has done the analysis on Right angled triangular ribs.

Parameters considered were 

| Reynolds number (Re) | 3800 to 18,000 |
|----------------------|----------------|
| Correlative roughness pitch ($P/e$) | 7.14 to 35.71 |
| Correlative roughness height ($e/Dh$) | 0.021 to 0.042 |
| Rib height ($e$) | 0.7 to 1.4mm |

They observed that 2.3 times enhancement in heat transfer.

Tabish Alam et al.[5] Has done experimentation on Duct with V shaped perforated blocks with parameters respect to Reynolds number. The following parameters have been considered 

| Reynolds number (Re) | 2000 to 20000 |
|----------------------|----------------|
| Correlative roughness pitch ($P/e$) | 4 to 12 |
| Angle of attack ($\alpha$) | 60° |
| Correlative blockage height ratio ($e/H$) | 0.4 to 1.0 |
| Open area ratio ($\beta$) | 5%–25% |

They concluded that Maximum thermo-hydraulic performance is achieved at an open area ratio ($\beta$) 20%, relative roughness pitch ($P/e$) of 8 and its value is of the order of 3.
3) *Review on DPSAH:* 

A DPSAH is which air passes twice on the absorber that is air flows on both sides of the absorber plate.

Ho-Ming Yeh and Chii-Dong Ho[6] has done numerical analysis on DPSAH with fins attached to the collector.

The following parameters have been considered

| Width | B | Length | L | Height | H |
|-------|---|--------|---|--------|---|
| Reflux Ratio | R |
| Sub channel width B/2 |

The conclusions are Enhancement in collector efficiency achieves 13.8% for \( I_0 = 1100 \text{ W/m}^2 \), \( T_i = 298 \text{ K} \), \( m=0.01 \text{ kg/s} \) and \( R = 1. \)

Ravi Kant Ravi and R.P. Saini[7] has done analysis on Discrete Multi V shaped ribs and staggered ribs.

The parameters considered were

| Reynolds number (\( Re \)) | 2000–20000 |
| Correlative staggered rib pitch (\( p'/p \)) | 0.2–0.8 |
| Correlative staggered rib size (\( r/e \)) | 1–4 |
| Angle of attack | 60° |
| Correlative roughness width (\( W/w \)) | 5–8 |

They arrived at a conclusion that Increment in Nusselt number lies in the range of 2.91 to 4.52 and Increment in Friction factor lies in the range of 2.08 to 3.13.

Manish Kumar Tated et al.[8] Has done the experimentation on collector with W shaped ribs attached on both sides

The following parameters were considered

| Reynolds number | 6900 to 14000. |
| Inclination angle (\( \alpha \)) | 45° |
| Relative roughness height (\( e/Dh \)) | 0.044 |
| Relative roughness pitch (\( P/e \)) | 5 to 20 |
The conclusion described as Nusselt number has continual enhancement with raise in Reynolds number and Friction factor has continual reduction with increase in Reynolds number. 1.4 folds increment in Nusselt number in comparison to absorber with smooth plate has been observed.

S.S. Krishnananth and K. Kalidasa Murugavel[9] has conducted experimentation by using paraffin wax as phase change material for thermal energy storage

The following parameters were considered

Tilt angle $9^\circ$

| Total no. of pipes utilised | 6 |
|----------------------------|---|
| Pipe length                | 60 cm |
| Pipe inner diameter        | 4 cm |
| Pipe, outer diameter       | 4.6 cm |
| Weight of paraffin wax per Capsule | 0.595 kg |
| Solar radiation intensity  | 900w/m$^2$ |
| Location of capsules in the duct | 3 |

The following conclusions were made Air at uniform high temperature can be obtained as output throughout the day. The efficiency is also high even during sundown.

**Summarized report of results obtained from various researchers:**

**Table 2: Solar Single Pass Air Heater- Simulation based Investigation**

| S.No | Investigator | Type of Air Heater | Parameters | Results |
|------|--------------|--------------------|------------|---------|
| 1    | Shalini Rai et al.[1] | Absorber plate with offset fins | Fin Spacing: 1 cm to 5 cm, Mass flow rate: 50 kg/h, Solar insolation: 950 w/m$^2$ | Absorber efficiency decreases with raise in mass flow rate, Collector efficiency increase with low fin spacing and fin height |
| 2    | Anil Kumar[2] | Absorber plate with 'V' shaped ribs | $P/e=10$, $\alpha=60^\circ$, $c/D=0.043$ | 1.7 times enhanced heat transfer compared to smooth plate |
| 3    | Anil Kumar[2] | Absorber plate with Multi 'V' shaped ribs | $P/e=10$, $\alpha=60^\circ$, $c/D=0.043$, $W/w=6$ | 4.7 times enhanced heat transfer compared to smooth plate |
| 4    | Brij Bhushan and Ranjit Singh[3] | Protrusions on collector | Solar insolation: 600 to 1000 w/m$^2$, Correlative long way length ($L/e$): 25.0–37.5, Correlative short way length ($S/e$): 18.75–37.5, Correlative print diameter ($d/D$): 0.147–0.367 | Correlative long way length ($L/e$): 31.25, Correlative short way length ($S/e$): 31.25, Correlative print diameter ($d/D$): 0.294 |
Kumar and Saini[10]  
Discrete Multi V Shaped ribs  
Correlative roughness pitch (P/e) 10  
Angle of attack (α) 60°  
Correlative roughness height (e/D) 0.043  
Duct aspect ratio (W/H) 12  
Correlative roughness width (W/w) 6  
Correlative gap distance(Gd/Lv) 0.55  
Nusselt number has an increase of 5.54 to 6.32 folds. Maximum value is obtained corresponding to Relative gap width of 1.0

Gawande et al.[4]  
Arc Shaped ribs  
Reynolds number (Re) 3800 to 18,000  
Prandtl's number (Pr) 0.7441  
Correlative roughness pitch (e/D) 7.14 to 35.71  
Duct aspect ratio(W/H) 5  
Heat flux 1000W/m².  
In correspondence to relative width ratio of 6.0 the Thermal performance is 3.67.

Gawande et al.[11]  
Circular vortex generator in the inlet section  
Reynolds number (Re) 3800 to 18,000  
Rib height (e) 1 mm  
Correlative roughness height (e/Dh) 0.03  
Correlative roughness pitch (P/e) 10 to 25  
Heat flux 1000W/m².  
1.06 times the enhanced heat transfer

Anil Kumar and Man-Hoe Kim[12]  
Multi ‘V’ type perforated baffles  
Heat flux 1000 W/m²  
Angle of attack (α) 60°  
Reynolds number (Re) 3000 to 10000  
Decrement in Friction factor is observed with increase in the Reynolds number Multi V-down perforated baffles produces higher Nu

Pandey et al.[13]  
Multi arc shaped roughness  
Reynolds number (Re) 2100–21,000  
Correlative roughness pitch (p/e) 8  
Arc angle (a) 60°  
Correlative roughness height (e/D) 0.044  
Aspect ratio (W/H) 10  
Nu and Nu ratios (Nu/Nus) increase with increase in Reynolds number

Chandra Prakash and R.P. Saini[14], [15]  
Spherical and inclined rib protrusions  
Reynolds number (Re) 2000–20000  
Correlative roughness pitch (P/e) 15,20, 25, 30  
Angle of attack 9α) 60°  
Correlative roughness height (e/D) 0.04  
Duct aspect ratio (W/H) 12  
Spherical and inclined rib protrusions produce an average increase in Nusselt number of 2.88 folds and Friction factor of 1.58 folds in comparison to smooth plate

Table 3: Solar Single Pass Air Heater – Experimental Investigation

| S.N0 | Investigator | Type of Air Heater | Parameters | Results |
|------|--------------|--------------------|------------|---------|
| 1    | Zeliha Deniz ALTA et al.[16] | Collector with a tilt angle | Tilt angle 35°, Air velocity 2m/s | For the air flow velocity of 1, 2, 3, and 4 m/s Mean energy efficiencies Were 42.5%, 53.4%, 59.0%, and 62.5% respectively. |
| 2    | Tabish Alam et al.[5] | Duct with ‘V’ shaped perforated blocks | Reynolds number (Re) 2000–20000, Correlative pitch ratio(P/e) 4–12, Angle of attack (α) 60°, Correlative blockage height ratio (e/H) 0.4–1.0, Open area ratio (β) 5%–25% | Maximum thermo-hydraulic performance is obtained for an open area ratio (β) of 20%, relative pitch ratio (P/e) of 8 and its value is of the order of 3. |
| Page | Author(s) | Material/Description | Formula/Parameter | Note |
|------|-----------|----------------------|-------------------|------|
| 3    | Amol Wadhawan et al.[11] | Using phase changing material for thermal energy storage in the ducts | \( Sp = \text{distance between centres of two adjacent pipes} = 44 \text{ mm} \) \( D = \text{diameter of pipes} = 15 \text{ mm} \) \( Sp/D = 2.93 \) | Time for which the energy is stored in the PCM Increases with decreases in the mass flow rate. An average increase of 86.54% is observed in rise in output Air temperature. |
| 4    | Devecioglu and Vedet Oruc[17] | Using porous absorber plate | Tilt angle 15 Porous surface width 220mm Meshing 3x3mm | Thermal efficiency increased by 25% to 57% Thermo-hydraulic efficiency increased by 14% to 44% |
| 5    | Alok Kumar Rohit and Atul lanjewar[18] | Absorber plate with ‘W’ discrete ribs | Angle of attack 45° Solar insolation 1500w/m² Roughness pitch 10 | For W-discrete up increment in Nusselt number is 2.36 folds and For W-discrete down increment in Nusselt number is 2.60 folds in comparison to smooth duct. Increment in friction factor is 1.79 folds for W-discrete up and 1.73 folds for W-discrete down as compared to smooth duct. |
| 6    | Sunil Chamoli[19] | V down perforated baffle roughened rectangular channel | Aspect ratio 10 Heat flux intensity 1000w/m² Reynolds number 4000 to 20000 | Maximum Nusselt number 121.69 Minimum Friction factor 0.031 |
| 7    | S.K. Saini and R.P. Saini[20] | Roughened duct with Arc shaped ribs | Reynolds number (Re) 2000 to 17000 Correlative pitch (p/e) 10 Correlative angle of attack (a/90) 0.3333 to 0.6666 Duct aspect ratio (W/H) 12 Correlative roughness height (e/d) 0.0213 to 0.0422 | 3.8 times the enhancement in Nusselt number. 1.75 times enhancement in Friction factor. |
| 8    | Gabhane et al.[21] | Multiple ‘C’ shaped ribs on collector | Reynolds number (Re) 3000 to 15000 Relative roughness pitch (P/e) 8, 16, 24, 32, 40 Angle of attack (α) 30 to 75 Correlative roughness height (e/Dh) 0.02 Rib height (e) 2 mm Duct Aspect Ratio (W/H) 10 Transverse pitch 75 mm | Maximum Nusselt number obtained is 415. Friction factor is 0.031. Thermo-hydraulic performance parameter is 3.48. |
| 9    | Sukhmeet Singh[22] | Discrete ‘V’ down ribs as roughness | Reynolds number (Re) 3000 to 15000 Correlative roughness pitch (p/e) 4 to 12 Angle of attack (α) 30 to 75 Correlative roughness height (e/Dh) 0.015 to 0.043 Correlative gap position (d/w) 0.2 to 0.8 Correlative gap width (g/e) 0.5 to 2.0 | Nusselt number increased by 51.4% Friction factor has increased by 26.5%. |
| 10   | Arvind Kumar et al.[23] | Discrete ‘W’ shaped ribs | Reynolds number (Re) 3000 to 15000 Correlative roughness pitch (p/e) 10 Rib angle of attack (α) 30 to 75 Correlative roughness height (e/Dh) 0.0168 to 0.0338 Rib height (e) 0.75 to 1.5 Aspect ratio of duct, AR 8:1 Heat flux 900W/m² | Maximum enhancement of Nusselt number has Found to be 2.16 by creating artificial roughness. Maximum enhancement in Friction factor has been found to be 2.75 times that of smooth duct for an angle of attack of 60°. |
Anil Kumar et al. [24] Discrete Multiple ‘V’ ribs | Reynolds number (Re) 2000 to 20000 Correlation roughness pitch (P/e) 10 Angle of attack (α) 60 Correlation roughness height (e/D) 0.043 Correlation roughness width (W/w) 6 Duct aspect ratio (W/H) 12 | Nusselt number increases by 5.54 to 6.32 folds.

Khushmeet Kumar et al. [25] Duct with ‘S’ shaped ribs | Reynolds number (Re) 2400 to 20000. Correlation roughness pitch (P/e) 4 to 16 Angle of attack (α) 30° to 75° Correlation roughness height (e/Dh) 0.026 to 0.057 Relative gap width (g/e) 1 Relative staggered rib size (w/e) 4.5 Relative staggered rib pitch (p/P) 0.65 | Maximum increase in heat transfer (Nu) and friction factor (f) is observed in correspondence to relative arc angle (α/90) value of 0.6667 and relative roughness height (e/Dh) value of 0.043.

Narinderpal Singh Deo et al. [26] Multigap V-down ribs combined with staggered ribs | Reynolds number (Re) 4000 to 12000 Correlation roughness Pitch (P/e) 4 to 14 Angle of attack (α) 40 to 80 Correlation roughness height (e/Dh) 0.026 to 0.057 Relative gap width (g/e) 1 Relative staggered rib size (w/e) 4.5 Relative staggered rib pitch (p/P) 0.65 | Maximum increment in Nusselt number is 3.34. Maximum increment in Thermo-hydraulic performance is 2.45. Maximum increment in Friction factor is 3.38 folds that of smooth plate.

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Table 4: Solar Double Pass Air Heater – Simulation based Investigation

| S.N0 | Investigator | Type of Air Heater | Parameters | Results |
|------|--------------|--------------------|------------|--------|
| 1    | Ho-Ming Yeh and Chii-Dong Ho [6] | Fins are attached on the collector | Width B Length L Height H Reflux Ratio R Sub channel width B/2 | Enhancement in collector efficiency achieves 13.8% for \( I_0 = 1100 \text{ W/m}^2, T_i = 298 \text{ K}, m = 0.01 \text{ kg/s and } R = 1 \) |
| 2    | Brij Bhushan Prasad et al. [27] | Multiple Arc shaped baffles | Reynolds number 2000 to 17000 Attack-angle(α) 30°-75° | Thermal efficiency is found to be 78.00% |
| 3    | Mahdi Hedayatizadeh et al. [28] | Collector with ‘V’ corrugations | Tilt angle 0°-75° Reynolds number 2000 to 15000 | Maximum exergy efficiency of 6.27% is found. |
| 4    | Paisarn Naphon [29] | Porous media on the absorber plate | Nu = 0.0333Re0.6Pr1.3 \( \text{Ha} = 5.7 + 3.8V_H \), Ha convective heat transfer coefficient \( \text{De} = 4WH/(2W+2H) \), \( V = 1\text{m/s} \), Heat flux intensity = 1w/m² | Thermal efficiency increases by 25.9% |
| 5    | Paisarn Naphon [30] | Absorber plate attached with longitudinal fins | Nu = 0.018 Re 0.8 Pr 0.4 Reynolds number 2300 to 6000 \( V = 1\text{m/s} \), Heat flux intensity = 1w/m² | Increasing the height and number of fins increases Thermal efficiency. Increase in height and number of fins decreases Entropy generation. |
Gravel gives slightly better performance than limestone. High temperature is obtained with low porosity of packed bed.

Increment in Nusselt number lies in the range of 2.91 to 4.52. Increment in Friction factor lies in the range of 2.08 to 3.13

Maximum values of the efficiency obtained with and without PCM were 63.53% and 68.23%, respectively as PCM absorbs energy.

Table 5: Solar Double Pass Air Heater – Experimental Investigation

| S.NO | Investigator | Type of Air Heater | Parameters | Results |
|------|--------------|--------------------|------------|---------|
| 1    | Kaushik Patel et al. [33] | Collector with baffles, longitudinal fins and porous media | Baffles (400X65)-8No.s / (200X65)-16No.s Fins 900X65 – (4+3=7No.s) Metallic wiry sponge 75 – diameter and 75- height | Maximum efficiency has been observed in the DPSAH with metallic wiry Sponge in comparison to the other. |
| 2    | Manish Kumar Tated et al. [8] | Collector with ‘W’ shaped ribs attached on both sides | Reynolds number 6900 to 14000. Inclination angle (α) 45° Correlative roughness height(e/Dh) 0.044 Correlative roughness pitch (p/e) 5 to 20 | Nusselt number has continual enhancement with increase in Reynolds number. Decrement in Friction factor is observed continuously with increase in Reynolds number. 1.4 times enhancement in Nusselt number. |
| 3    | Muhammad Sajawal et al. [34] | Phase change material contained in finned tubes attached to collector | Inner Diameter = 36 mm Outer Diameter = 60 mm, For Semi-Circular Tube Outer Diameter = 50 mm, for Circular Tube No. of Semi-Circular Tubes = 5 No. of Circular Tubes = 6 mass/finned tube = 0.271 kg PCM is paraffin wax | Thermal efficiency is almost 15% higher due to the thermal storage Medium (PCM) used. |
| 4    | Bhupendra Gupta et al. [35] | Porous media type | Inclination angle 24° Solar insolation 900w/m2 Orifice diameter 12mm No. of holes 3 | Double flow has higher efficiency than the single flow Usage of porous media increase the system efficiency and the outlet temperature |
| 5    | S.S. Krishnaman and K. Kalidasa Murugavel [9] | Phase change material paraffin wax is used as thermal energy storage | Tilt angle 9° Pipe, inner diameter 4 cm Pipe, outer diameter 4.6 cm Pipe length 60 cm Total no. of pipes 6 Weight paraffin per Capsule 0.595 kg. Solar radiation intensity 900w/m2 | Air at uniform high temperature can be obtained as output throughout the day. The efficiency is also high even during sundown |
|   | Authors/Method | Description | Results/Findings |
|---|---------------|-------------|-----------------|
| 6 | Aldabbagh et al.[36] | Using Wire Mesh as packing bed | Maximum of 83.65% efficiency can be obtained by using a porous media. |
| 7 | Md. Washim Akram and Md. Redwan Islam[37] | Using Black coated Wire Mesh | Porosity measured in this experiment is 0.83. 22% higher Thermal efficiency than without Wire Mesh. |
| 8 | Sudhanshu Dogra[38] | Transverse ribs on the absorber plate | Efficiency increases with the increase in Reynolds number. Maximum value of effective efficiency is observed corresponding to relative roughness height of 0.044 and relative roughness pitch of 10 |
| 9 | El-Sebaii et al.[39] | V – corrugated absorber plate | Has higher thermal performance compared to flat plate, fins and baffles attached to absorber plate. Thermal performance increases with increase in recyle ratio. |
| 10 | Chii-Dong Ho et al.[40] | Cross corrugated absorber plate | Has higher thermal performance compared to flat plate, fins and baffles attached to absorber plate. Thermal performance increases with increase in recyle ratio. |
| 11 | Raheleh Nowzari et al.[41] | Mesh layers as Absorber plate | Maximum of 83.65% efficiency |
| 12 | Sumit Joshi and L. Varshney[42] | Combination of broken Arc and Staggered ribs | The maximum value of Nusselt number obtained is 122.72. Maximum value of Friction factor obtained is 0.04077. 49.35% enhancement in Nusselt number. 19.56% enhancement in Friction factor |
| 13 | Sudhanshu Dogra et al.[43] | Transverse ribs attached to the absorber plate | Nusselt number increase by 1.06 times compared to flat plate. 1.6 times enhancement in heat transfer. |
| 14 | A.P. Omojaro and L.B.Y. Aldabbagh[44] | Using Fins and Steel Wire Mesh as absorber | Maximum Thermal efficiency 63.74% obtained. 7.19-4% higher efficiency than single pass heater. |
| 15 | Ravi Kant Ravi and R.P. Saini[45] | Combination of discrete multi V shaped and staggered ribs | Nusselt number and Friction factor are maximum at maximum at \( \theta/t = 2.5 \). Nusselt number ratio for double pass and single pass is 3.4 Friction factor ratio for double pass and single pass is 2.5 |
| 16 | Satyender Singh[46] | Collector with inline, | Thermo-Hydraulic efficiency is found to be 79%. |
4) Conclusion:

From the experiments conducted by various researchers it can be concluded that DPSAH’s have better thermal performance compared to SPSAH’s and also discrete ribs provide higher efficiency than continuous ribs.

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