"Experimental Investigation of Photovoltaic Panel Cooling System Assisted With Artificial Roughness"

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ABSTRACT

Photovoltaic cell converts solar energy into electrical energy. These systems combine a photovoltaic cell with a solar module i.e. converts solar radiation into electricity. A PV module converts 6-20% incident solar radiation into electricity according to its type and climate conditions. Mainly incident solar radiation is converted into heat which increases the temperature of Photovoltaic module and reduces its efficiency.The photovoltaic cell can be effectively improved by using artificial roughness in different forms, shapes and sizes. Artificial roughness is provided in the form of different geometries such as ribs, dimple shape roughness, wire mesh, baffles, delta winglets etc.The various roughness element geometries employed in solar cell in terms of heat transfer, friction factor and flow simulation geometries. Correlations developed for heat transfer and friction factor for different roughness geometries by various investigators in solar cell. By using roughness geometry on photovoltaic panel with working fluid of cooling air the temperature of solar panel decreases then efficiency of solar panel increases.

Keywords: Photovoltaic Cell, Solar, Electrical, Roughness Geometry, Friction Factor, Heat Transfer. Thermal efficiency, electrical efficiency,

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1. INTRODUCTION:

When Sun light on a photovoltaic (PV) cell, it may be reflected, absorbed, or pass right through it. The PV cell is composed of semiconductor material, which combines some properties of metals and some properties of insulators. That makes it uniquely capable of converting light into electricity. When light is absorbed by a semiconductor, photons of light can transfer their energy to electrons, allowing the electrons to flow through the material as electrical current. This current flows out of the semiconductor to metal contacts and then makes its way out to power your home and the rest of the electric grid. In the recent span, when there is a continuous demand of energy for the economic progress and industrialization, renewable sources are playing vital role in this regard. They are used to design high routine heat transfer systems. Heat transfer enhancement in these thermal systems has numerous applications including cooling of electronics systems, industries, agriculture, space heating etc. Photovoltaic cells have an important advantage over PV module, collecting materials attached to conventional PV modules. On the other hand, the air type requires a high volume of air flow to obtain good thermal efficiency and bring up the corresponding matters of large diameter tubing, noise and fan losses. The large tubing required may cause problems, especially in retrofitting.

Ribs used in cooling channel and heat exchanger channel are most commonly used passive heat transfer techniques. So that the work related to fluid flow and heat transfer in ribbed channel is go so far. Each rib on downstream separates the flow, recirculation and impinges on channel wall and these are the main reason for heat transfer enhancement in such channel. The use of rib in heat exchanger not only increase the heat transfer rate but also substantial the pressure loss. The rib arrangement and geometry resulting in different heat transfer distribution by changing the flow field. Therefore by making the modification in rib geometry we can increase the heat transfer rate but at the same time we need to consider the pressure drop also because it increases significantly.

2. LITERATURE REVIEW:

2.1 Vipin B. Gawande, A. S. Dhoble, D. B. Zodpe :

The performance characteristics of a solar heater and heat exchangers can be effectively improved by using artificial roughness in different forms, shapes and sizes. Artificial roughness is provided in the form of different geometries such as ribs, dimple shape roughness, wire mesh, baffles, delta winglets etc. The paper has given geometrical parameters for individual geometry, specifying the heat transfer enhancement in terms of Nusselt number and pressure drop penalty in terms of friction factor values.

2.2 Huan-Liang Tsai, Chieh-Yen Hsu And Yung-Chou Chen:

This paper presents the efficiency enhancement for a novel photovoltaic/thermal (PVT) air collector in which PV and thermal efficiency is simultaneously enhanced with a reciprocal aid. With the encapsulation of solar cells directly on a fin-type heat sink, the direct conduction mechanism and the convective area for the thermal transportation are effectively increased.

2.3 Jin-Hee Kim, Se-Hyeon Park, Jun-Tae Kim:

In this study, a PVT air collector with a mono-crystalline PV module was designed, and an experiment was performed in order to confirm its electrical and thermal performance in an outdoor environment. The experimental results indicated that the thermal and electrical efficiencies of the PVT collector were, on average, 22% and about 15%, respectively. Therefore, it was concluded that the heated air taken from the PVT collector can be supplied into the ventilation system in building as pre-heated fresh air, and contribute to better electrical performance at the same time.

2.4 R. Kunnemeyer, T. N. Anderson, M. Duke, J. K. Carson:

The idea of concentrating solar energy to increase the output of photovoltaic and solar thermal collectors is an area that has received significant attention.. Also, it was shown that the V-trough could be made of a durable (long life) stainless steel, rather than the more reflective aluminum, while still offering a 25% increase in incident radiation over a typical year. However it was noted that modifications would be needed to improve cooling and to increase the thermal efficiency by reducing heat losses.

2.5 Tony Ho, Samuel S. Mao And Ralph Greif:

The solar concentration limit for densely packed, high-concentrated photovoltaic (HCPV) cells was analyzed for a novel two-phase cooling design. Eight working fluids were examined in the two-phase cooling analysis: R134a, R11, R113, R114, R123, R141b, water, and ammonia.. This observed higher concentration limit for water and ammonia at a given flow rate can be attributed to their larger heat capacities and latent heats when compared with the organic fluids examined.

2.6 Karima E. Amori, Mustafa Adil Abd-AlRaheem:

In the present work a comparative study for thermal and electrical performance of different hybrid photovoltaic/thermal collector's designs for Iraq climate conditions have been carried out. Four different types of air based hybrid PV/T collectors have been manufactured and tested. Three collectors consist of four main parts namely, channel duct, glass cover, axial fan to circulate air and two PV panels in parallel connection. The measured parameters are, the temperature of the upper and the lower surfaces of the PV panels, air temperature along the collector, air flow rate, pressure drop, power produced by solar cell, and climate conditions such as wind speed, solar radiation and ambient temperature.

2.7 J. Manohar, J. Sundhar Singh Paul Joseph, J. Lakshmipathy & M. Satishkumar:

The double pipe heat exchanger is a device used to transfer heat from hot fluid from cold fluid. In which the inside tube carrying hot water and outside tube carrying cold water. Considerable enhancements were demonstrated in the present work by using numbers of rectangular fins fitted over inner tube along its length.. It is show that the suggested method of heat transfer enhancements is much more effective than existing methods, since in an increase in the heat transfer co-efficient.

2.8 S. H. Barhatte, M. R. Chopade:

Extended surfaces, commonly known as fins, often offer an economical and trouble free solution in many situations demanding natural convection heat transfer. In the present study, the fin flats are modified by removing the central fin portion by cutting a triangular notch. This dissertation report presents an experimental analysis of the results obtained over a range of fin heights and heat dissipation rate.

2.9 Sandhya Mirapalli, Kishore. P. S:

Heat transfer by convection between a surface and the fluid surrounding can be increased by attaching to the surface called fins. Rectangular fin and triangular fins are straight fins. Triangular fins are attractive, since for an equal heat transfer it requires much less volume than rectangular fin. In an air-cooled engine, rectangular and triangular fins are provided on the periphery of engine cylinder. Heat transfer analysis is carried out by placing rectangular and then triangular fins. Analysis is carried out by varying temperatures on the surface of the cylinder from 200 ºC to 600ºC and varying length from 6 cm to 14 cm.

2.10 Kunpeng Guo, Nan Zhang, Robin Smith:

A major challenge in designing optimal multi-stream plate-fin heat exchangers is the large number of combinations of standardized fin geometries for various fin types to choose from, which adds discrete aspects to an already complicated design problem. In this work, a new design algorithm is proposed to address this issue. By treating basic fin geometries such as plate spacing, fin pitch, fin length and fin thickness as continuous variables for all the fin types, different fin types are characterized based on the work published by different researchers.

2.11 Dipak Saurabh P, And S. G. Taji:

Fin arrays on horizontal and vertical surfaces are used in variety of engineering applications to dissipate heat to the surroundings.The purpose of the present study is to investigate thoroughly the possibility of performance improvement of such arrays by providing triangular perforation at the centre and suggest for selection of optimum notch dimensions and spacing by analyzing variety of fin arrangements.

3. OBJECTIVES

1. To evaluate the heat transfer performance of different shapes of rib.

2. Comparison of heat transfer performances of different shapes of ribs and validate data by comparing it without rib.

3. To study the pressure drop and frictional factor at different velocity.

4. To study the effect of varying Reynolds number on various parameters such as heat transfer rate, heat transfer coefficient, friction factor etc.

5. To compare the experimental values of heat transfer coefficient with the theoretical values.

6. To study the thermal and electrical efficiency of solar panel.

4. EXPERIMENTAL SETUP

The actual experimental setup is as shown in Figure 4.1.The experimental setup consist of various measuring devices such as photovoltaic cell, rectangular duct, ribs, blower, thermocouple, U-tube manometer, digital temperature indicator, thermocouple, Rectangular duct consist of rectangular channel, different shapes of roughness geometry mounted on test plate, and blower .The PV panel are connected in inclined and mounted in a mild steel frame. Air flow enters the duct formed between PV panel and back copper plate. The air duct was sealed carefully to avoid hot air leakage. Air has been passed through the duct by using a single phase blower of power of (600 W) at the duct outlet. The specifications for PV module used in this work are given in table 1 respectively. K type thermocouples are used to measure the temperatures of air, PV module, and ambient temperatures. Five of thermocouples are evenly distributed at the back surface of the modules. One thermocouple is fixed on atmosphere. Second thermocouple is fixed on roof. Third thermocouple is fixed on inlet air temperature. Fourth thermocouple is fixed on plate. Fifth thermocouple is fixed on outlet air temperature. All thermocouples are connected to a selector switch type which is connected to a K type digital temperature indicator. Manometer is used to measure the pressure drop due to different roughness geometry placed inside the duct.

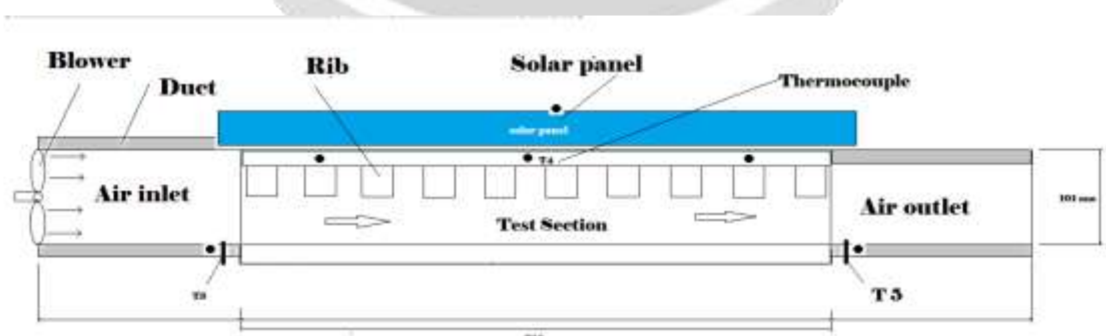

Fig. 4.1 Schematic diagram of rectangular duct

Fig 4.2 Experimental setup

Table 1 PV panel Specifications

Electrical data	Value
Module type	NSA40
Maximum power (Pmax)	40 W
Maximum power voltage (Vmp)	17.84 V
Maximum power current (Imp)	2.25 Amp
Open circuit voltage (Voc)	21.95 V
Short circuit current (Isc)	2.44 Amp
Operating temperature	25 °C
Mechanical data	
Cell type	Poly-crystalline
No. of cells and cells arrangement	60 (6 * 10)
Dimensions (mm)	762 * 457.2 * 25 mm
Weight	7 – 9 kg
Front cover	Tempered glass
Frame material	Anodized Aluminum Alloy

5. PROCEDURE

Firstly the experimentation is carried out when the no artificial roughness geometry present inside the duct and back side of PV panel. Before start the blower to measure the temperature of atmosphere as well as test section by using thermocouple. Then start the blower the air is passed through the panel inlet to the without artificial geometry with increasing flow rate (0.91, 0.97, 1.07, 1.17 kg/s) to measure the temperature of atmosphere, roof, inlet, plate, outlet and test section by using thermocouple. Due to sun rays the temperature of solar panel increases to the reduction of temperature of the solar panel for the cooling to start the blower. Velocity is measured with anemometer and pressure drop is measured by using manometer and note down the reading. In this phase, different artificial roughness geometry (Transverse, Inclined, V-up continuous, V- down continuous) fitted on the surface of a plate are used to increasing the cooling rate of PV panel and also used enhance the heat transfer rate. Take out the previous test without ribs and then replace it with the help of artificial roughness geometry. Start the blower the air is passed through the panel inlet to the panel by using various artificial roughness geometry with increasing flow rate (0.91, 0.97, 1.07, 1.17 kg/s) to measure the temperature of atmosphere, roof, inlet, plate, outlet and test section by using thermocouple. Take the reading of all the thermocouples (T1, T2, T3, T4, and T5) at an interval of half an hour.
Calculate the thermal efficiency and heat transfer rate comparing with and without artificial roughness geometry. Start the set up and then follow the same procedure as above and note down the readings.

6. DATA CALCULATION AND ANALYSIS

1. Bulk mean temperature

$$T_{mean} = (T_{b1} + T_{b2}) /2$$

Where, Tb1 and Tb2 are the temperatures of base plate at two points in °C.

2. Hydraulic diameter

$D_h = 4A/P$

Where,

D_h = Hydraulic diameter, m

A = Area of channel, m^2

P = Perimeter of channel, m

P = 2*(W+H)

A = W×H

W = width

H = height

3. Mass flow rate

m = ρAV

ρ = Density Kg/m^3

A = Area m^2

V = Velocity m/s

m = mass flow rate kg/sec

4. Heat transfer rate

$Q = m*cp*(T_{b2} - T_{b1})$

Q = heat transfer rate, W

m = mass flow rate kg/sec

Cp = specific heat of air J/Kg –K

T_{b1} = bulk temp at inlet °C

T_{b2} = bulk temp at exit °C

5. Heat transfer coefficient

$h = Q/ As*(Tw- (T_{b1+} T_{b2})/2)$

h = heat transfer coefficient W/ m^2 k

Q = heat transfer rate, W

As = Heat transfer area =3.14* D* L= m^2

D = diameter of tube in m.

L = length of tube in m.

Tw = wall surface temp °C

T_{b1} = bulk temp at inlet °C

T_{b2} = bulk temp at exit °C

6. Pressure drop

$\Delta P = \rho \times g \times h$

ρ = Density Kg/m^3

g = acceleration due to gravity m/s^2

h = manometer height in m

7. Reynolds's Number

$Re = (\rho * D_h * v) / \mu$

ρ = Density Kg/m^3

D = diameter of tube in m.

V = velocity in m/s

μ = Absolute viscosity N-s/m^2

8.Nusselt Number

$$Nu = h^* D_h / k$$

h = heat transfer coefficient W/ m^2 k

D_h = hydraulic diameter mm.

K = thermal conductivity W/m-k

9.Friction factor

$$f = \Delta P \times 2 \times D_h / Lt \times \rho \times v^2$$

ΔP = pressure drop N/m^2

D = diameter in m

Lt = length in m.

ρ = Density Kg/m^3

V = velocity in m/s

10. Thermal efficiency

ηth = m Cp (To-Ti)/ Gap

m = mass flow rate Kg/s

Cp = specific heat of air J/Kg-K

To = outlet temp °C

Ti = inlet temp °C

Gap = solar panel area

11. Electrical efficiency

e = Ppv /Gap

Ppv = PV module power

Gap = solar panel area

Comb = th + e

th = thermal efficiency

e = electrical efficiency

7. RESULT AND DISCUSSION

The electrical and thermal performance of the PV panel was measured and the results are analyzed.

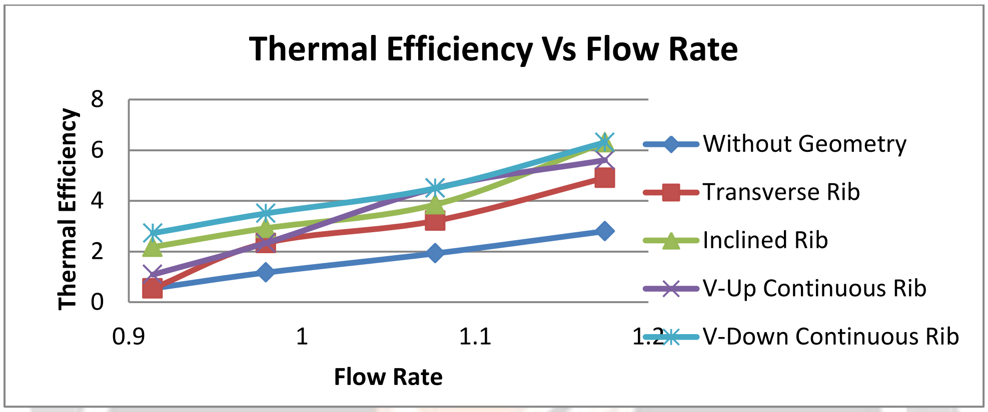

Fig 1 the variation of the thermal efficiency with flow rate

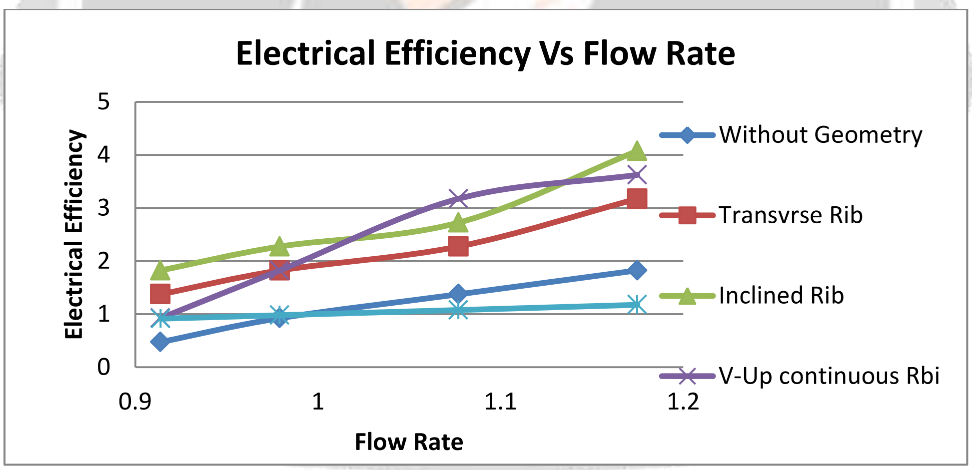

Fig 2 the variation of the electrical efficiency with flow rate

The temperature of solar panel is 1 °C is increases the efficiency of solar panel is 0.45% decreases. Hence when the cooling system is used the temperature is decreases and efficiency of solar panel is increases and higher range of cooling heat transfer rate and other analysis hence they used various artificial roughness geometry. In the beginning, the experiment is performed without artificial roughness geometry rib at the time the roof temperature of the panel is obtained with the use of air circulation system on without artificial roughness geometry rib with different flow rate (0.91, 0.97, 1.07, 1.17 kg/s) heat the thermal efficiency is obtained 0.59% and same operation is performed in gradually increasing air flow rate then thermal efficiency and electrical efficiency is improved gradually. Fig 1 and 2 increase the air flow rate then increase the thermal and electrical efficiency. The air is passed through the without artificial roughness geometry the heat transfer rate is increased with increasing air flow rate. The air is circulated to the air inlet and air outlet then temperature difference is obtained 3- 4°C. The air flow rate is increases then temperature difference of air is also increases. The experiment is performed with Transverse artificial roughness geometry rib. Is fitted inside the panel air flow on the surface of plate with different flow rate and start the air blower due to rib turbulence is increased in the air flow. The heat transfer rate is increased with the use of transverse rib the temperature difference between of inlet air and outlet air through the panel was about 5-7^0 C with cooling air system can be turned on to perform the air cooling operation which helps improves the solar cell thermal efficiency and electrical efficiency by 4.90 %-3.17%.The experiment is performed with Inclined artificial roughness geometry rib. With the use of cooling air system the heat transfer rate is increased compared to transverse rib with the temperature difference between air inlet and outlet section is 7-9°C for without rib. The thermal efficiency and electrical efficiency is also increased 6.30% - 4.07% comparing to without rib and transverse rib. The experiment is performed with V-up continuous artificial roughness geometry. The thermal efficiency and electrical efficiency is small higher with the use different flow rate air circulation system and heat transfer rate is slightly increased. The temperature difference between inlet air and exhaust air through the panel is 7-8°C .The thermal efficiency and electrical efficiency of solar panel is 5.60 % and 3.62 %.

The experiment is performed with V-down continuous artificial roughness geometry. With the use of different flow rate in cooling system the heat transfer rate is higher compare with the other ribs and thermal and electrical efficiency is also increased higher by 6.30 % and 4.07 % with the temperature difference between inlet air and outlet air through the panel was about 8-10°C. The thermal and electrical efficiency is improved increasingly with the terms of overall efficiency. The performance of the PV panel is improved.

8. CONCLUSION

Experimental investigation has been carried out in the rectangular duct to study the effect of various artificial roughness geometry ribs on heat transfer enhancement. Following conclusion are made i.e. the heat transfer in rectangular duct with different artificial roughness geometry ribs is found to be more as compared to without ribs. The experimental setup is validated with Dittus- Boelter and Blausis corelation. The results are in good agreement within less heat transfer and friction factor. It is concluded that V-down continuous rib is having more heat transfer coefficient, is higher than that of rectangular duct without rib, working with Reynolds number in the range of 15000-21000. In V-down continuous rib heat transfer coefficient is more because Reynolds number increases Nusselt number also increases. Experimental results within 6- 7% increase thermal efficiency and electrical efficiency 3-4%. With increase in a Reynolds number the flow is getting more turbulent. Therefore heat transfer rate is increasing. Nusselt number is the ratio of convective heat transfer to conduction heat transfer. When we are increasing air flow velocity heat transfer rate is increasing. Therefore the increase in heat transfer occurs because more turbulence is generated within the duct by using various artificial roughness geometry ribs and also increasing the performance of the PV panel as compared to without ribs.

9. REFERENCES:

1] “Effect Of roughness geometries on heat transfer enhancement In Solar thermal systems” – Review of Vipin B.Gawande, A.S.Dhoble, D.B.Zodpe ‘Renewable and sustainable energy reviews’ 32(2014)347–378.

2] “Efficiency Enhancement of Novel Photovoltaic-Thermal (PVT) Air Collector”Huan-Liang Tsaia, Chieh-Yen Hsub and Yung-Chou Chenc *Pplied Mechanics And Materials Vols. 494-495* (2014) At(2014)TransTechPublications,Switzerland.

3] “Experimental Performance Of A Photovoltaic Thermal Air Collector Jin-Hee Kima,Se-Hyeon Parkb, Jun-Tae Kimc,* SHC 2013, International Conference On Solar Heating And Cooling For Buildings And Industry September 23-25, 2013, Freiburg, Germany Energy Procedia 48 (2014) 888 – 894.

4] “Performance of a V-Trough Photovoltaic/Thermal Concentrator” R. Ku¨Nnemeyer A, T.N.Anderson B, M.Duke , J.K. Carson A Solar Energy 101 (2014) 19–27.

5] “The Impact of Cooling On Cell Temperature and the Practical Solar Concentration Limits for Photovoltaic”Tony Ho,Y, Samuel S. Mao And Ralph Greif ‘International Journal Of Energy Research Int’. J. Energy Res. 2011; 35:1250–1257Published Online 3 September 2010 in Wiley Online Library (Wileyonlinelibrary.Com). Doi: 10.1002/Er.1778.

6] “Field Study of Various Air Based Photovoltaic/Thermal Hybrid Solar Collectors” Karima E. Amori*, Mustafa Adil Abd-Alraheem Renewable Energy 63 (2014) 402e414.

7] “Experimental Study on Fabrication of Finned Type Counter Flow Heat Exchanger” J. Manohar*, J. Sundhar Singh Paul Joseph*, J. Lakshmipathy* & M. Sathishkumar *2016.*

8] *”*Experimental and Computational Analysis and Optimization for Heat transfer Through Fins With Triangular Notch.” S. H. Barhatte, M. R. Chopade.

9] “Heat Transfer Analysis on a Triangular Fin” Sandhya Mirapalli1, Kishore.P.S2.‘International Journal of Engineering Trends and Technology’ (IJETT) – Volume 19 Number 5 – Jan 2015 19 Number 5 – Jan 2015.

10]“Optimisation of Fin Selection and Thermal Design of Counter-Current Plate-Fin Heat Exchangers.” Kunpeng Guo, Nan Zhang, Robin Smith ‘Centre For Process Integration, School Of Chemical Engineering and Analytical Science,’ University Of Manchester, Manchester M13 9PL, UK Accepted 23 November 2014.

11] “Convection Heat Transfer from Horizontal Rectangular Fin Array Having Triangular Perforations” Dipak Saurabh And S. G.Taji ‘International Journal of Current Engineering and Technology’ E-ISSN 2277 – 4106, P-ISSN 2347 – 5161 Accepted 03 March 2016.