Economic Cooling of Solar PV Modules

S. Karthik[1] Abhilash K Prabhu[2] Viralkumar J. Patel[3]
[1]Department of Mechanical Engineering [2]Department of Aerospace Engineering [3]Department of Chemical Engineering
[1,2,3]University of Petroleum and Energy Studies, Dehradun

Abstract— The vortex tube is a refrigerating equipment that produces both cold as well as hot air at both opposite ends. The vortex tube's construction is such that it is made up of a hollow tube of either metallic or fibre components having a nozzle for letting in of compressed air and a diaphragm or an orifice for controlling the flow rate of air. When compressed air passes through a nozzle into the diaphragm of the vortex tube, the air forms a spiral shaped vortex, that causes the heating up of air, and when this air returns back, it cools down rapidly, producing a cooling effect. The main study in the Vortex tube is the study of the temperature distribution of the rotating air. This effect was first discovered by Ranque and later by Hilsch and hence this effect is called Ranque-Hilsch effect. The second law of thermodynamics forbids a 100%-efficient solar cell. More specifically, Carnot's applies to photovoltaics and any other solar energy system, where the hot side of the "heat engine" is the temperature of the sun and the cold side is the ambient temperature on earth. The result is, for a system with sunlight concentration, the maximum efficiency is ~85%, and for a system that does not track the sun, the maximum efficiency is ~55%. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. Hence, the cooling of the module is very important. For a solar module, the open circuit voltage decreases with increase in voltage. The open-circuit voltage decreases with temperature because of the temperature dependence of I_o. With the help of the vortex tube cooling technology, we can reduce solar module heating economically and thereby reducing the heating effect on the Voltage difference, which will effectively increase the output from solar panels. The heating and after effects of cooling will be modelled through CFD for better understanding of the heat flow pattern over the panel.

Key words: Economic Cooling, Solar PV Modules

I. Introduction

The effect of temperature has an adverse impact on the performance of a solar pv module. It depends upon three parameters

1) Short circuit current I_{sc}
2) Open circuit voltage V_{oc}
3) Fill factor

With the increase in temperature, the following are the effects on the above mentioned parameters,

- I_{sc} increases
- V_{oc} decreases
- Fill factor decreases

The solar pv panel works best with in a temperature range of 23- 27 0C. Normally cooling is done by natural draft, but for efficient cooling here vortex effect is being used. To implement the vortex technology we vortex tube.

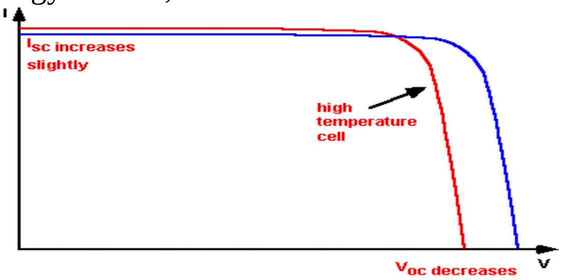


Fig. 1: The effect of temperature on the IV characteristics of a solar cell.

The vortex tube is a refrigerating equipment that generates both cold as well as hot air at both ends of the tube. The vortex tube's construction is usually of a hollow tube of either metallic or fibre components having a nozzle for letting in of compressed air tangentially and a diaphragm or an orifice for controlling the flow rate of air. When compressed air passes through a nozzle into the vortex tube, the air forms a spiral shaped vortex, that causes the heating up of air and when this air returns back, it cools down rapidly, and further passing through a diaphragm produces a cooling effect. This effect was first discovered by Ranque and later by Hilsch and hence this effect is called Ranque-Hilsch effect.

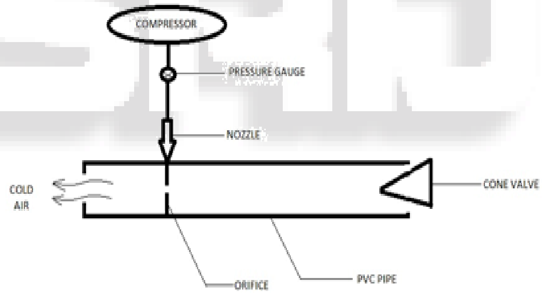


Fig. 2: Schematic of vortex tube

Separating cold and hot streams by using vortex tube can be used in industrial applications such as cooling equipment and refrigerators . This device suits for these applications because its light ,simple and more importantly it is compact . Many researches have been carried out in order to identify the factor which affects Vortex tube performance.

Here, an analysis has been conducted to determine the effect of geometrical parameters on vortex tube performance and air is used as the working fluid. To achieve the maximum proficiency of a vortex tube, form the data which obtained experimentally, optimum values for cold orifice diameter to the VT inlet diameter (d / D) and the length of VT to its inlet diameter (L/ D) for this experiment is proposed.

II. Literature Review

reason for failure for performance in pv panel: The operating temperature of a solar cell is determined from:-

- Ambient air temperature

- By the characteristics of the module in which it is encapsulated
- By the intensity of the sunlight falling on it
- By other variables such as wind speed

Normally solar panel efficiency is maximum at 25^{o}C. In order to maintain the optimum efficiency the solar module needs to be maintained at a temperature near to 25^{o}C. The normal rooftop temperature is given by 65^{o}C.

The reasons for failure in performance are due to:-

- As the temperature increases, the band gap Eg decreases.
- Strong temperature of reverse saturation current
- Characteristics of module in which solar cell is situated.

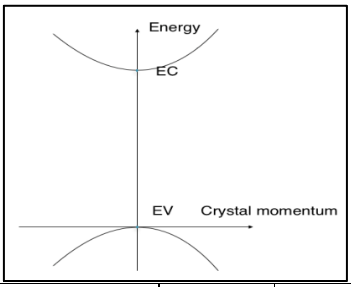


Fig. 3(a): Band Gap representation

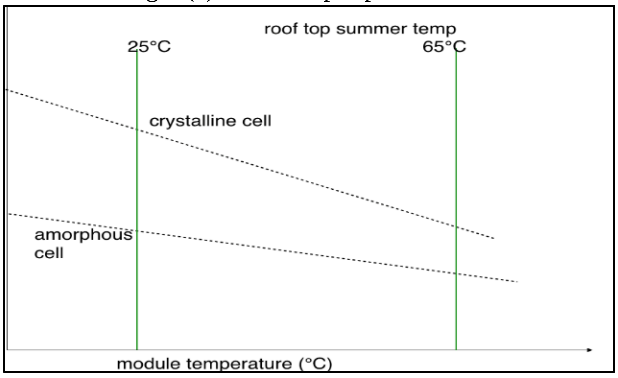


Fig. (b): Temperaturevs Efficiency Characteristic

After initial experiments, a lot of researchers tried a lot of modifications on the vortex tube to increase its performance. It is found from the previous scientist's records that each and every one of them used various L/D ratios and each one of them was a result of hit and trial method.

The list is given below regarding the modifications and customizations:-

SCIENTIST	L (inch)	D (inch)	Nozzle dia (inch)	year	Cold end orifice dia (dc)	dr=dc/D
TAKAHAMA	317	2	0.5	1980	-	-
REYNOLDS	48	3	0.12	1985	127	0.42
AHLBORN	24	1	-	1997	0.328	0.33
C.RAO	8	0.63	0.12	2005	0.16	0.25
NINMBALKAR	10	0.75	0.162	2011	0.38	0.50

III. EXPERIMENTAL SETUP

A. *Design of Vortex Tube*

The main aim is to achieve a Vortex path of air. Since the nozzle placed for the vortex tube is tangential, air entering through it gets a swirling (vortex) motion inside the cylindrical tube. The air attains a high velocity, during the swirling motion and travels towards the cone valve (in the end of the hot side) as a spiral vortex. When the swirling flow reaches the end, it is resisted by the partially opened valve. Due to the conversion of kinetic energy, the pressure of the air near the valve increases and a reversed axial flow through the low pressure case. By controlling the opening of the valve, the proportion of cold air and hot air and their temperatures can be varied. For obtaining the maximum temperature difference at cold end, the ratio L/D should be maintained in the range of 30 ≤ L/D ≤ 60. Hence, considering the length to be 113.03cm and diameter to be 2.05cm, we get the L/D ratio to be in the range. The material of the vortex tube used in this case is PVC.

Tube inner diameter	2.057 cm	d
Cold plate orifice diameter	1.028 cm	0.5d
Inlet nozzle diameter	0.3 cm	0.14d
No. Of nozzle inlet	5	Depending on air flow rate
Hot end length	92.71 cm	45d
Cold end length	20.32 cm	10d
Pressure range	0-2 bar	Experimental setup

B. *Selection of Design*

Reasons for selection of PVC material and the used dimensions for the design:-

1) For obtaining the maximum temperature difference at cold end, the ratio L/D should be maintained in the range of 30 ≤ L/D ≤ 60. Hence, considering the length to be 113.03cm and diameter to be 2.05cm, we get the L/D ratio to be in the range.
2) PVC pipe is used for maximum reduction in the overall cost of the product and to test if it provides the same effect as other materials.

REYNOLD'S MODEL	OUR MODEL
pipe length = 120 cm	pipe length=113.03 cm
Diameter = 7.62 cm	Diameter= 2.05 cm
L/D ratio = 15	L/D ratio = 55.03

The problem with Reynold's L/D ratio is that it does not satisfy the condition 30<L/D<60. Hence, the next best possibility was to choose the diameter proposed by Ahlborn, which fulfilled the required condition.

IV. CALCULATION

density of air $\rho_a = P_a/(RT_a)$ (1)

$= \frac{1.01325 \times 10^5}{287 \times 308} = 1.176$ kg/m^3

flow rate $v_a = cd \times a \times (2gh_a)^{1/2}$ (2)

$h_a = (h_w \rho_w)/\rho_a$ (3)

$= (8.4 \times 10^{-2} \times 10^3) / 1.176$

= 71.428 m of air

Hence,

$v_a = 0.6 \times \{\pi \times (0.012)^2\}/4 \times [2 \times 9.81 \times 71.428]^{1/2}$ (4)

$= 2.539 \times 10^{-3}$ m^3/s

flow rate at NTP, $v_{ntp} = (v_a T_o)/T_a$ (5)

T_o = normal temperature=273 K
T_a= ambient temperature = 308K
v_{ntp}= {2.539 x 10^{-3} x 273} / 308
= 2.215 x 10^{-3} m^3/s

mass flow rate at NTP = $v_{ntp}\ \rho_a$ (6)

= 2.215 x 10^{-3} x 1.176
= 2.6 x 10^{-3} kg/s

refrigeration effect = $\dot{m}$ Cp ΔT (7)

where $\dot{m}$= mass flow rate
= 2.6 x 10^{-3} x 1.005 x (308 - 298)
= 26.13 W

$$\text{Work done} = \frac{3600}{E} \times \frac{2}{t} \times 10^3\ \text{W} \qquad (8)$$

where E= energy meter constant for compressor used
t = time taken for 10 seconds for the energy disc to rotate
Coefficient of performance (COP)

= Refrigeration effect/ work done (9)

= 26.13 / 188.67 = 0.13

Calculation for optimum tilt angle, assuming location to be Delhi (lat. 21^o) and the sum overhead at 12:00 noon.

Declination angle on July 1st of a year:

δ= 23.45sin{(360/365)*(284+n)}; n=44 for July 1^{st} (10)

δ= -13.94^o $\simeq$-14^o

Zenith angle θ_z

$= \cos^{-1}(\sin\Phi\sin\delta + \cos\Phi\cos\delta\cos\omega)$ (11)

Here, Φ = latitude= 21^o and ω = 0^o for 12:00 noon.
Hence $\theta_z = 35^o$
For solar azimuth angle,

$\gamma_s = \cos^{-1}$ {$(\cos\theta_z \sin\Phi - \sin\delta) / (\sin\theta_z \cos\Phi)$} (12)

Substituting the values for the respective angles, $\gamma_s = 0$
Hence slope angle β is given by

$\beta = \tan^{-1}(\tan\theta_z \cos\gamma_s)$ (13)

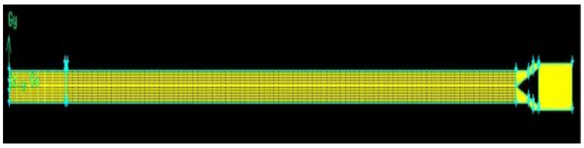
= 35^o

V. RESULT

For the vortex tube, the experimental results conducted at an ambient temperature of 35oC were:-

Temperature Analysis	
Pressure (Bar)	Cold End Temperature (^{0}c)
0	18.13
0.5	16.91
1	16.15
1.5	14.63
2	13.98

A. *The CFD Model obtained*



VI. CONCLUSIONS

- Vortex tube is a handy portable refrigeration system that requires very less power input for functioning. Hence cooling is achieved at all terrains and locations.
- Efficient method than natural cooling and still economical.
- Increases the life of the solar PV module by maintaining the panel temperature nearly at 25^o C at all times.

REFERENCES

[1] M. G. Ranque, 1933, “Experiences sur la detente giratoire avec production simulanees d’un echappement d’air chaud et d’air froid”, Journal de Physique et le Radium (in French), Supplement, Vol. 7, No. 4, pp. 112-114.

[2] R. Hilsch, 1947, “The Use of the Expansion of Gases in a Centrifugal Field as Cooling Process”, The Review of Scientific Instruments, Vol. 18, No. 2, pp. 108-113.

[3] T. T. Cockerill, 1998, “Thermodynamics and Fluid Mechanics of a Ranque-Hilsch Vortex Tube”, Ph.D. Thesis, University of Cambridge, Department of Engineering.

[4] J. P. Hartnett, and E. R. G. Eckert, 1957, “Experimental Study of the Velocity and temperature Distribution in a High-Velocity Vortex-Type Flow”, Transactions of the ASME, Vol. 79, No. 4, pp. 751-758.

[5] B. K. Ahlborn, and J. M. Gordon, 2000, “The Vortex Tube as a Classical Thermodynamic Refrigeration Cycle”, Journal of Applied Physics, Vol. 88., No. 6, pp. 3645-3653.

[6] B. Ahlborn, and S. Groves, 1997, “Secondary Flow in a Vortex Tube”, Fluid Dyn. Research, Vol. 21, pp. 73-86.

[7] 7.Christiana Honsberg and Stuart Bowden(2001), Effect of Temperature (Available at: http://www.pveducation.org/pvcdrom/solar-cell-operation/effect-of-temperature.