EFFECT OF PERFORATED RECTANGULAR BAFFLE WITH DIFFERENT OPENING SIZES AND PRESSURE DROP IN COOLING OF SOLAR POWER PACK USING CFD

1LAKSHMINARASIMHA. N, 2M.S. RAJAGOPAL, 3RAVISHANKAR. M.K, 4VINOD, 5TAYABULLA, 6SYED MUKRAM

1IGBC AP and Assistant Professor, Mechanical Engineering Department, MVJCE, Bengaluru
2Professor and Head, Mechanical Engineering Department, GAT, Bengaluru
3Head and Associate Professor, Mechanical Engineering Department, MVJCE, Bengaluru
4, 5, 6UG Students, Mechanical Engineering, MVJCE, Bengaluru
E-mail: 1nlnsimha25@gmail.com, 2msrajagopal@yahoo.com

Abstract- The heat generating electrical devices such as Battery Bank, Inverter and Controller are housed in an enclosure called Solar Power Pack (SPP). This numerical study is mainly focused on effect of Baffle with perforation of different opening sizes such as 25% and 35% of total area of Baffle, ensuring uniform air motion in an enclosure in cooling these devices such that they operate less than the range of operating temperature. Also this study comprises of investigating the effect of pressure drop helps in minimizing power consumption/ pumping power cost. ANSYS FLUENT is used for numerical analysis. Numerical results satisfy analytical results.

Keywords- Solar Power Pack, enclosure, CFD, Effect, cooling, Baffle, pressure drop, FLUENT

I. INTRODUCTION

SPP is an enclosure housing heat generating equipments such as Battery Bank, Controller and Inverter. Figure 1, shows the schematic of SPP.

The working model of SPP consists of Battery Bank, Controller and Inverter. Solar energy is converted to electricity through Solar PV array. Optimization of Solar charging and Battery over charging/ deep discharging is prevented by Controlling Unit or Power Conditioning Unit (PCU). Battery Bank is used to store electricity, DC power is converted to AC using Inverter, further which AC power is utilized to all basic electrical and electronic appliances (see Figure 1).

Using CFD, analysis has been carried out for both fluid flow and heat, in order to ensure adequate airflow in an enclosure and to meet the cooling requirements of high heat generating devices, so that these devices operate less than their temperature limit. To achieve this, enclosure is been provided with perforated Baffle with different opening sizes of 25% and 35% of total area of Baffle to provide uniform air motion in an enclosure and ensure adequate amount of air- flows at hot spot regions. Also pressure drop is been investigated which helps the engineers in minimizing the power consumption. The results obtained are graphically represented with color postscript output/ flow visualizations.

II. LITERATURE SURVEY

Literature survey has been carried out focusing on industrial aspects in design and thermal management meeting its industrial needs. The various data sheets, graphs discussed are deployed by thermal design engineers which are a ready reckoner for designing any preliminary electronic system. Further survey carried out is based on research journal papers to understand tools and methodology for thermal management of electrical and electronic devices. Summaries of few important journals are listed below.

Lakshminarasimha. N, Dr.M.S.Rajagopal, et al., [1], [2015], Paper comprises of study on SPP in Overall evaluation design involving ventilation and cooling and Optimization study on positioning inlet and exhaust and their sizes for adequate air entry and exit. Also analysis has been carried out by providing baffle with no openings and Perforated Rectangular baffle with 50% opening of total area of Baffle and also pressure drop has been investigated. The results are represented graphically through velocity and temperature contours. Paper concludes that considering both temperature and pressure drop the Rectangular perforated Baffle with 50% opening of total area of Baffle is better compared to baffle with no perforated vents. Lakshminarasimha. N, [2], [2015], Paper deals with the CFD analysis of forced
Effect Of Perforated Rectangular Baffle With Different Opening Sizes And Pressure Drop In Cooling Of Solar Power Pack Using CFD

Mahendra Wankhede, et al. [3], [2010], Paper deals with CFD analysis of Aluminium enclosure. Enclosure consists of 100W heat generating PCBs. Paper concludes that use of internal fans reduces enclosure internal air temperature by 20-25% compared to enclosure with no fans.

Hoffman, Pentair Company, [4], [2003], this technical manual is a ready reckoner for designing an electronic enclosure. Also this manual is helpful for engineers in preliminary design stage of any electronic enclosure in evaluating any kind/type of design aspects.

Surveyed literatures helped in understanding the thermal system with high heat load dissipations and lead to carry out further analysis on SPP.

III. CFD PROCESS

ANSYS- Fluent is been used for SPP analysis. This CFD code works on three main basic elements: (i) preprocessor, (ii) solver and (iii) post processing (see Figure 2).

Figure 2: CFD process

As same, SPP analysis has been carried out in following steps as in Figure 3.

Figure 3: Steps in SPP analysis

ANSYS products provide highly simplified way for combined modeling, meshing and analysis.

3.1 Modeling

The 3D geometry model of SPP is as shown in Figure 4. It consists of Battery Bank, Controller and Inverter. The geometry model is symmetry. Inlet is provided to the side wall and exhaust fan is provided at top-centered position of rear wall of SPP.

Figure 4: 3D Wire frame Model of SPP

3.2 Meshing

SPP Model is created with mapped hexagonal mesh. All models with different Baffles are meshed keeping minimum two lakhs elements and nodes [1]. The isometric view mesh model of SPP is as shown in Figure 5 and Zoomed view of mesh is as shown in Figure 6.

Figure 5: ISO view 3D mesh model of SPP

Figure 6: Zoomed view of mesh model
3.3 Boundary conditions
The SPP domain consists of inlet, outlet, symmetry plane, Battery Bank, controller and Inverter. The outlet is with exhaust fan boundary condition with 285 CFM. Heat generating devices are provided with coupled thermal conditions. The mid-plane of SPP is provided with symmetry wall boundary condition. Walls are stationary and with no slip boundary conditions. (See Figure 7).

Since the flow is turbulent, another equation comes into light that is Standard K-epsilon model which consists of two transport equations that are solved in Fluent code, as said earlier one is turbulent kinetic energy (see eqn. 1) and second equation is turbulent dissipation rate (see eqn. 2).

\[
\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_i} \left[ \mu + \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_i} \right] + C_{\text{eq}} (G_k + C_{\text{eb}}) - S_k \quad \cdots \cdots \cdots \text{(eqn. 1)}
\]

And

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_i} \left[ \mu + \frac{\mu_t}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_i} \right] + C_{\text{eq}} (\varepsilon_k + C_{\text{eb}}) - C_{\text{eq}} \rho \varepsilon^2_k + S_\varepsilon \quad \cdots \cdots \cdots \text{(eqn. 2)}
\]

Where, turbulent or eddy viscosity, \( \mu_t = \rho \varepsilon \frac{k}{\varepsilon} \) and \( G_k \) & \( G_\varepsilon \) represents the generation of turbulence kinetic energy due to mean velocity gradients and buoyancy. \( Y_M \) represents the contribution of the fluctuating dilation in compressible turbulence to the overall dissipation rate \([10] \).

3.4 Solution controls
The flow is steady and turbulent; the model selected for present analysis is Standard K-epsilon model, hence it consists of two equations: (i) Turbulent Kinetic energy and (ii) Turbulent dissipation rate that are solved for obtaining the results. To solve momentum and turbulence parameter SIMPLE discretization is used. A residual value for governing equations is maintained for 1e-6 except energy is maintained at 1e-7. The solution is initialized by standard initialization.

3.5 Mathematical Models
The fundamental physics principles and Governing equations of fluid solved in Fluent code are as shown in Figure 8.

3.6 Results and Discussion
Through literature survey, for enclosure with temperature rise of 4°C and rectangular perforated Baffle with 50% opening of its total area the results obtained is as below Table 1 \([1] \).

<table>
<thead>
<tr>
<th>Baffle type</th>
<th>Devices</th>
<th>Temperature in °C</th>
<th>Pressure drop in N/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular perforated Baffle</td>
<td>Battery Bank</td>
<td>39.33</td>
<td>13.1</td>
</tr>
<tr>
<td>with 50% opening of total area</td>
<td>Controller</td>
<td>38.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inverter</td>
<td>40.56</td>
<td></td>
</tr>
</tbody>
</table>

As further optimization study, the rectangular Baffle is provided with different opening sizes (see Figure 9) and results obtained are as in Table 2. The area of Baffle is maintained constant. This study is carried to understand the effect and extent of cooling on these devices for different opening sizes on Baffle, so that it helps in maintaining reduced temperature operating condition and increased life of heat generating devices for given heat load conditions. Figure 10 (a) and 10 (b) shows the temperature contour plot for case 1 and 2. Also pressure drop is been investigated. As pressure drop is directly proportional to power consumption in an enclosure and hence reduced pressure drop decreases the power consumption or pumping power cost for an enclosure. The power consumption/pumping power cost can be found out by using eqn. 3.

In order to pump fluid in a steady state, the power requirement is given and calculated by:

\[ \text{Power} = \int v \cdot dp = \frac{m}{\rho} \Delta p \quad \cdots \cdots \cdots \text{(eqn.3)} \]

Where, \( \Delta p \) is pressure drop= \( P_{in} - P_{out} \) in N/m².
\( \dot{m} \) is mass flow rate in kg/s, \( \rho \) is density of fluid in kg/m\(^3\).

### Table 2: Results for different opening sizes on rectangular perforated Baffle

<table>
<thead>
<tr>
<th>Cases</th>
<th>Baffle opening to its total area</th>
<th>Devices</th>
<th>Temperature in °C</th>
<th>Pressure drop in N/m(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25%</td>
<td>Battery Bank</td>
<td>39.07</td>
<td>9.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controller</td>
<td>39.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inverter</td>
<td>39.81</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>35%</td>
<td>Battery Bank</td>
<td>38.65</td>
<td>9.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controller</td>
<td>37.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inverter</td>
<td>40.85</td>
<td></td>
</tr>
</tbody>
</table>

Case 1: Comparing Table 1 with 25% opening of a Baffle (see Table 2), battery bank temperature remains same with negligible decrease in temperature. Controller temperature found to be increased by one degree Celsius, where as Inverter temperature decreased by one degree Celsius and pressure drop found to be reduced by about 3 N/m\(^2\). Approximately all these devices are at 39 °C.

Case 2: Comparing Table 1 with 35% opening of a Baffle (see Table 2), battery bank temperature and Controller temperature decreased by one degree Celsius, where as Inverter temperature remains same with negligible increase in temperature. Pressure drop found to be reduced by about 3 N/m\(^2\).

![Figure 9: Rectangular Baffle with different opening sizes](image)

Figure 10 (a): Temperature contour plot for case 1

Figure 10 (b): Temperature contour plot for case 2

Figure 11 shows the velocity stream line plot for cases 1 & 2. The plot highlights the distribution of air in an enclosure.

![Figure 11: Velocity Streamline plots for case 1 and case 2](image)

### 3.7 Comparison of results

Below Table 3, shows the result comparison for Enclosure Temperature rise from analysis, chart (see Figure 12) and formula (see eqn. 3).

### Table 3: Result comparison for enclosure temperature rise

<table>
<thead>
<tr>
<th>Result from</th>
<th>Enclosure rise (( \Delta T )) in °C</th>
<th>Temperature rise (( \Delta T )) in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Chart</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Formula</td>
<td>3.75</td>
<td></td>
</tr>
</tbody>
</table>

From chart (Figure 12), \( \Delta T = 9°F \) or \( 4°C \)

![Figure 12: Fan selection chart](image)
Q= \dot{m} \times C_{p} \times \Delta T \quad \text{(eqn.4)}

Where, \( Q \) is total heat load in W, \( \dot{m} \) is mass flow rate in kg/s, \( C_{p} \) is specific heat of air in kJ/kg k, \( \Delta T \) is temperature rise in K or °C.

Also Inlet velocity obtained through analysis is compared with analytical calculations. The solution is checked for both mass and heat balance and is maintained as obtained results are converged results.

CONCLUSIONS

The below following conclusions drawn from the CFD analysis of SPP consisting heat generating devices such as Battery Bank, Controller and Inverter are:

i. CFD is effective, powerful and less time consuming in determining maximum temperature, velocity and pressure drop
ii. Study involves effect of Rectangular Baffles for different open sizes to its total area and pressure drop
   a. 25% open to total area of Baffle
   b. 35% open to total area of Baffle
iii. From Literature survey, found results for 50% Baffle opening. Comparing 50% open rectangular Baffle with Baffles of 25% and 35% opening sizes, the temperature values obtained seems similar but there is considerable pressure drop in an enclosure.
iv. Instead 50% opening size, 25% and 35% opening size baffles are recommended in terms of pressure drop since pressure drop reduces the power consumption in an enclosure.
v. Present work can be extended for transient analysis and considering outdoor radiation effect

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REFERENCES