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CFD Analysis of Electronic Cabinet with High power devices and Fin heat sink

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ABSTRACT : *Any electronic cabinet/enclosure consists of heat generating electronic components, as heat generated by the electronic components in an enclosure shortens the life of electronic components leading to severe damage or failure of the system. Research shows that every 10^0C temperature rise above room temperature of the enclosure, the life of the electronic components is cut in half. Hence for any electronic systems, cooling becomes a major design consideration, economical and optimum solution to keep the electronic components to its operating limit.Therefore in the present work numerical analysis is been carried out using ANSYS Fluent on electronic cabinet of size 358mm X 78mm X 252mm consisting five high power devices as a heat source, each dissipating heat of 30W. The cabinet is forced cooled using two exhaust fans each of 48 CFM. The analysis is carried providing fin heat sink on heat generating source and compared with heat source with no fin heat sink. The analysis results show that the cabinet temperature rise is below 10^0C and better cooling is achieved for the heat source with fin heat sink. Also analysis results obtained satisfy with analytical calculations.*
Keywords *- Electronic cabinet, Fin heat sink, ANSYS Fluent*

I. INTRODUCTION

Electronic and Electrical enclosures consist of heat generating devices or components which are the major source of heat dissipation in an enclosure. Hence cooling is the most difficult and major task in designing any electronic cabinet/enclosures. Therefore electronic enclosures to be designed with proper airflow requirements, location of fans and positions of heat generating components placed in a cabinet, provided baffles and heat sinks as optional. Baffles provided in an enclosure ensure proper directed flow towards hot spots and heat sinks helps absorbing excessive or unwanted heat.

There are several cooling techniques such as Fin heat sink, Thermo electric coolers, Forced convection cooling, heat pipes etc. Present study is on heat source with fin heat sink provided fans to the cabinet. Cabinets with fans will improve cooling up to 10% [1].

Present numerical analysis is carried out using ANSYS Fluent on electronic cabinet consist heat sources and with and without fin heat sink. The parameters such as velocity and temperature variations in cabinet are studied, as CFD techniques helps the engineers to provide the optimum solution in cooling of electronic components.

II. LITERATURE SURVEY

Literature survey is carried out to understand the art of work in the field of Electronics cooling. Below are the few literatures which helped as ready reckoner to carry out the present work.

Hoffman Pentair Company, [1], [2003], this industrial technical data sheet helps as a ready reckoner in calculating the enclosure temperature rise, air flow requirements and also in choosing fan for an enclosure and it highlights about the effect of temperature on surface parameters of the enclosure.

Mahendra Wankede, et.al, [2], [2010], the study deals with both experimental and simulation on an aluminium enclosure with 100W heat generating source PCBs. The work concludes that there is 20% reduce in temperature of internal air using fans than enclosure without fans.

Lakshminarasimha N, [3], [2015], Study involves numerical investigation on electrical enclosure with forced convection cooling consist 150W heat power source. Study highlights analytical calculations for airflow requirements and enclosure temperature rise.

Bud Industries Inc, [4], [2007], this technical data sheet provides design tips for designing any electronic enclosures and also provides necessary basic formulas required for any design aspects of electronic enclosures.

Literatures found on present work are minimal though there are many literatures available on chip PCBs cooling and fins with different state of art of work. However effort has been made to carry out present work with available data's and literatures. Only few major literatures are discussed in this section remaining literatures are highlighted in the reference section.

III. METHODOLOGY

Basic steps in any numerical analysis consist of Geometry, Meshing and Analysis. Present work uses ANSYS product for Geometry, Meshing and Analysis, following succeeding sections discusses in detail.

3.1 Geometry

The 3D model of the cabinet is as shown in Fig. 1. It consists of the following:

1. Five high power devices or heat sources
2. Ten fin heat sink
3. Two exhaust fans
4. One inlet vent/opening
5. Backing plate

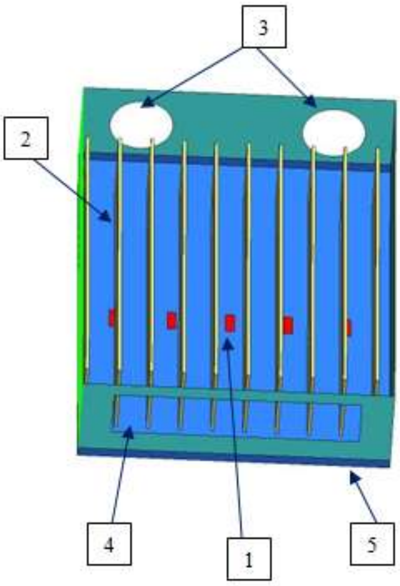

fig. 1: 3D model of Electronic Cabinet

The size of the cabinet is 358mm X 78mm X 252mm and fins are 2.5 mm thick and are equally offset to total 10 numbers. The inlet opening is provided at the left side of the cabinet and two exhaust fans are at the right side of the cabinet. The Backing plate is provided to separate the heat source side and fin side.

3.2 Meshing

The model is meshed with Hexagonal mesh elements as shown in Fig. 2a, also the cut plane and zoomed view of a meshed model is as shown in Fig. 2b and Fig. 2c. The model is meshed for varied number of elements for carrying out mesh independence test (see following section 1) and selected mesh through mesh independence test is used for further discussion results (see following section 2).

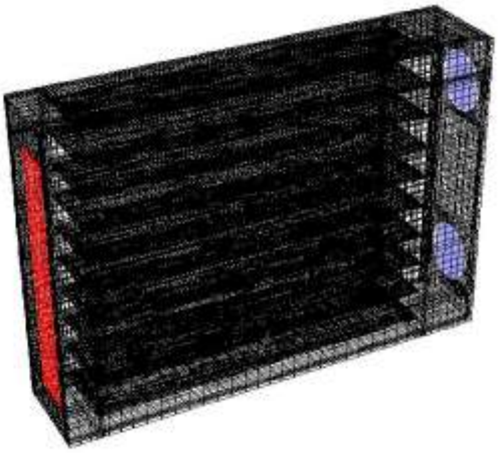

Fig. 2a: Hexagonal mesh

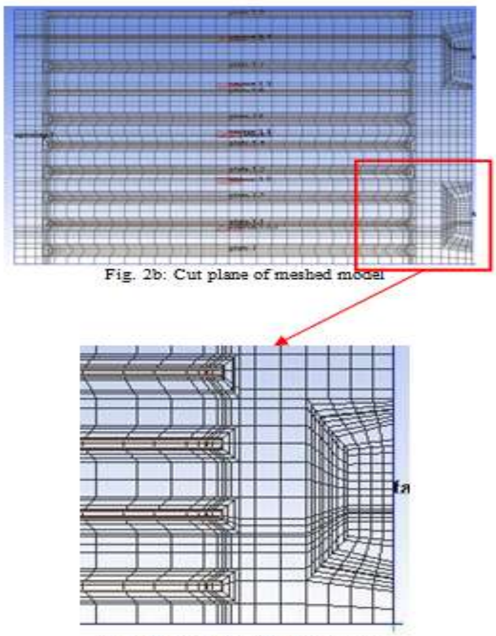

Fig. 2b: Cut plane of meshed model

Fig. 2c: Zoomed view of mesh plane

3.2.1 Mesh Independence Test: The graph was plotted for varied number of elements vs. converged temperature results of all the elements numbers as shown in Fig. 3. It is observed from the graph, from 142800 elements the curve becoming constant. Hence selecting the model meshed with 142800 elements for all the further discussion of results.

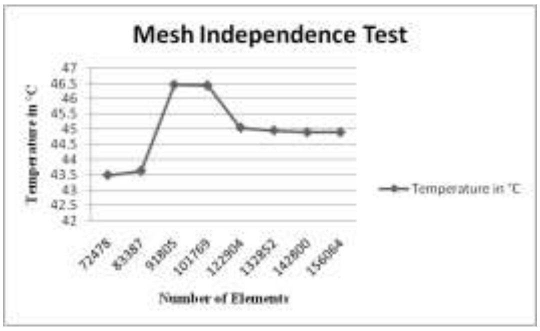

Fig. 3: Mesh Independence Test

3.2.2 Mesh convergence plot:

The mesh convergence plot for the 142800 elements meshed model and mesh was converged at 139 iterations is as shown in Fig. 4. The residual monitor for continuity, x- velocity, y- velocity, z velocity and k- epsilon is maintained to be 1e-3 and for energy 1e-7.

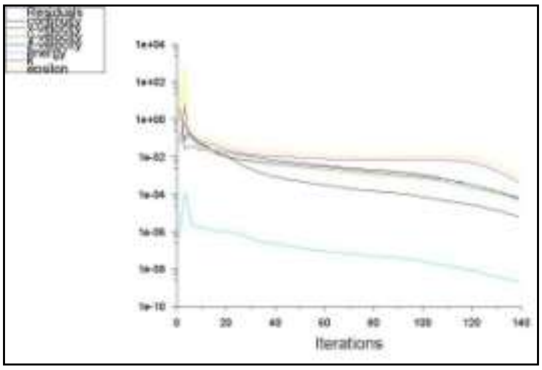

Fig. 4: Mesh convergence plot

3.3 Solution Methodology

In the present analysis, there are five high power devices as a heat sources each dissipating 30W. Hence total heat dissipated is 150W. Therefore to remove this heat, the cabinet requires the air flow of total 96 CFM. For efficient cooling of a cabinet two exhaust fans are selected of each 48 CFM (48 X 2= 96 CFM).

Total Air flow requirement in CFM, [4] required for the cabinet was calculated using eqn. 1:

Total CFM $= (1.76 \times Q)/\Delta T$ ………….. eqn. 1

$= (1.76 \times 150)/2.76$

= 95.65 ≈ 96 CFM

Where,

Q is Total heat dissipated in a cabinet in Watts

ΔT is Temperature rise in ^{0}C and is calculated using eqn. 4.

The heat sources are at heat flux and cabinet walls are at no slip boundary conditions. Inlet is at negative pressure condition since heat is removed through exhaust fans. The flow is considered to be steady and incompressible. Flow is of turbulent hence k- epsilon model is solved for obtaining the results. SIMPLE discretization scheme is used to solve the momentum equations and turbulent parameters.

IV. MATHEMATICAL MODELS

Every cell in the meshed model is converged for Mass, Momentum and Energy equations. Since the flow is turbulent, two more additional equations are solved i.e. turbulent Kinetic energy "k" (eqn. 2) and turbulent dissipation rate "epsilon" (eqn. 3).

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_M + S_k$$

……….. eqn. 2

And

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon}G_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon$$

…… eqn. 3

Where, turbulent or eddy viscosity, $\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$ and G_k& G_b 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, [5].

V. RESULTS AND DISCUSSION

The analysis was carried for cabinet providing fin heat sink and without fin heat sink, to understand the effect of fin heat sink on reduction in temperature of the heat generating sources. The results obtained from the analysis are as discussed in following sections:

5.1 Velocity contours

The velocity contour plots obtained for the cabinet without fin heat sink is as shown in Fig. 5 and cabinet with fin heat sink is as shown in Fig. 6.

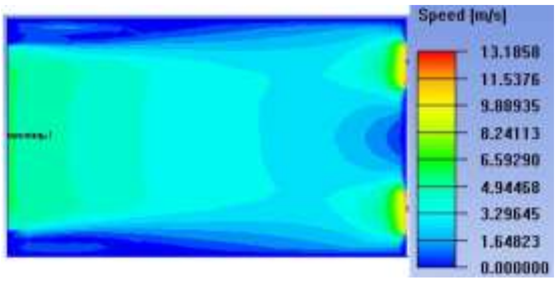

Fig. 5: Velocity contour- without fin heat sink

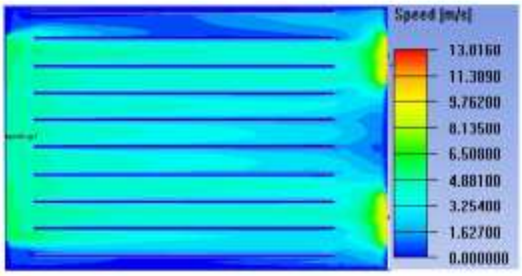

Fig. 6: Velocity contour- with fin heat sink

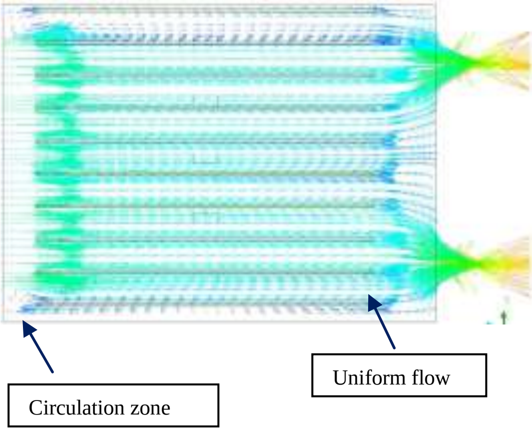

Fig 7: Velocity vector- with fin heat sink

Comparing Fig. 5 and Fig. 6, it is found that there is negligible variation in velocity. The maximum velocity for cabinet without fin heat sink found to be 13.2 m/s and cabinet with heat sink found to be 13.01m/s. For both the cases maximum velocity was found near exhaust fan.

Fig. 7, shows the velocity vector plot for cabinet with fin heat sink, it highlights that providing fins helps in uniform flow for air in the cabinet and also it determines the direction of flow and circulation zones.

5.2 Temperature contours

The temperature contour plots obtained for the cabinet without fin heat sink is as shown in Fig. 8 and cabinet with fin heat sink is as shown in Fig. 9.

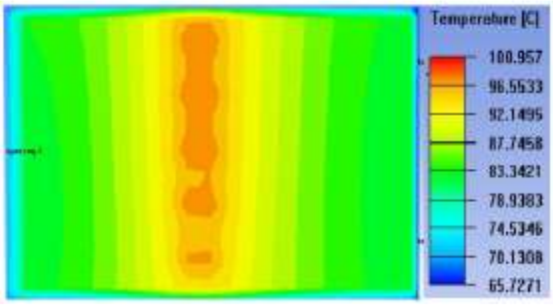

Fig. 8: Temperature contour- without fin heat sink

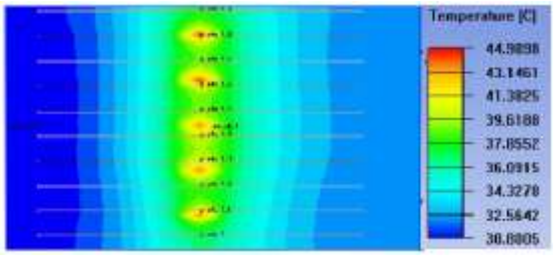

Fig. 9: Temperature contour- with fin heat sink

Comparing Fig. 8 and Fig. 9, it is found that there is huge reduction by 55% in temperature. The maximum temperature for cabinet without fin heat sink found to be 100℃ and cabinet with heat sink found to be 45℃. For both the cases maximum temperature was found at heat source. Also the temperature distribution along the fin length of 70mm (Fig. 10) is plotted; it is found that there is continuous reduction in temperature till the fin tip as shown in Fig. 11.

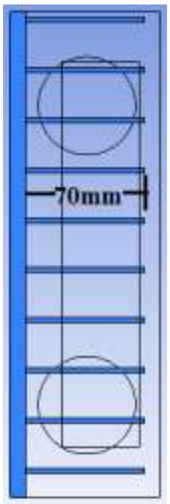

Fig. 10: Fin arrangement of 10 numbers of length 70 mm

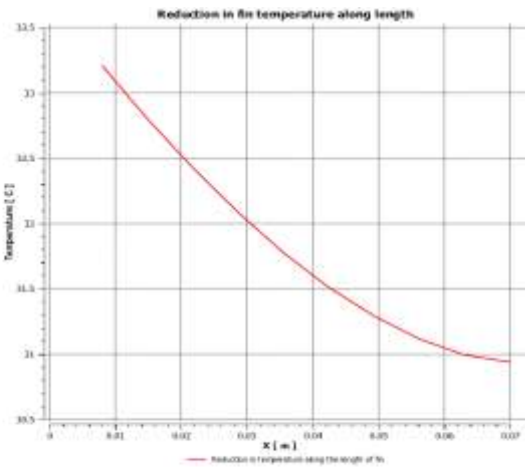

Fig. 11: Continuous reduction in fin temperature along the length till fin tip

VI. COMPARISON OF RESULTS

The results obtained through analysis and analytical calculations are compared and discussed in the following sections:

6.1 Temperature rise

The analysis result of temperature rise is validated with analytical result as following:

6.1.1Analyticalcalculation:

Analytically temperature rise of a cabinet can be calculated by using eqn. 4.

$Q = \dot{m}C_p\Delta T$ ………………. eqn. 4

$\dot{m} = \rho \times A \times V$

$= 1.2 \times 8.1073 \times 10^{-3} \times 5.55$

$= 0.054$ kg/s

Therefore, substituting the value of Q, C_p and $\dot{m}$ in eqn. 4,

Rearranging eqn. 4,

$$\Delta T = \frac{Q}{\dot{m}\, C_p}$$

$$= \frac{150}{0.054 \times 1005}$$

$= 2.76$°C

Where,

Q= Total heat dissipated in a cabinet in Watts

$\dot{m}$= mass flow rate in kg/s

ρ= Density of air= 1.2 kg/m^3

A= Area of inlet/outlet in m^2

V= Velocity at inlet or outlet in m/s

C_p= Specific heat of air = 1005 J/kg. K

ΔT = Temperature rise in °C

6.2.2 Analysis result: The result obtained for Temperature rise from analysis is as shown below,

```
Area-Weighted Average
 Static Temperature                    (k)
---------------------- --------------------
            fan_1-minz           295.95547
        fan_1_1_1-minz           296.02475
        opening_1-minz           293.14999
```

The temperature values at exhaust/outlet and inlet opening was found to be 296 K and 293 K. Hence 296 K (23°C) – 293 K (20°C) = 3°C. Therefore the Temperature rise in the cabinet is approximately 3°C.

Table 1, shows the comparison of results of Temperature rise from analysis and analytical calculation.

TABLE1COMPARISON OF RESULT OF TEMPERATURE RISE

Method	Temperature rise in °C
Analytical	**2.76**
Analysis	**3**

Therefore from Table 1, it is observed that the result obtained through analysis for a Temperature rise of a cabinet satisfies the analytical calculation.

6.2 Inlet velocity

Considering flow to be incompressible and applying continuity equation for inlet and outlet of the cabinet the velocity at inlet can be calculated using eqn. 5.

$A_iV_i = A_oV_o$ ………….. eqn. 5

Where,

A_i and A_o are the areas of inlet and outlet in m^2

V_i and V_o are the velocity at inlet and outlet in m/s

Since Area at the inlet and outlet is maintained same i.e. A_i=A_o, then V_i= V_o from eqn. 5.

6.2.1 Analytical calculation: Velocity at outlet, V_o= 96 CFM (from eqn. 1). Conversion of units from CFM into m/s is as shown below,

1 CFM = 0.00047 m^3/s, [6]

Therefore, 96 CFM= 0.04512 m^3/s= $\dot{Q}$ (flow rate)

Flow rate, $\dot{Q}$= A×V_o

Rearranging, V_o= $\dot{Q}$/A = 0.04512/8 x 10^{-3}

= 5.64 m/s = V_i

6.2.2 Analysis result: The result obtained for inlet velocity from analysis is as shown below,

```
     Area-Weighted Average
      Velocity Magnitude                 (m/s)
-------------------------- --------------------
             opening_1-minz           5.5746703
```

The velocity at the inlet opening was found to be 5.57 m/s.

Table 2, shows the comparison of results for the inlet velocity from analysis and analytical calculation.

TABLE2 COMPARISON OF RESULT OF INLET VELOCITY

Method	Inlet velocity in m/s
Analytical	**5.64**
Analysis	**5.57**

Therefore from Table 2, it is observed that the result obtained through analysis for inlet velocity of a cabinet satisfies the analytical calculation.

Also results are checked for mass balance and heat balance and hence satisfy.

VII. CONCLUSIONS

Analysis is carried out for the electronic cabinet consist of five high power devices each dissipating 30W. The cabinet is cooled through forced convection using two exhaust fans of each 48 CFM. The following conclusions drawn from the obtained results are:

1. Computational technique is a very effective method in determining the velocity and temperature in an electronic cabinet
2. Cabinet is analyzed for both with and without fin heat sink. It is found that better cooling is possible for a cabinet consist heat sources provided with fin heat sink than without fin heat sink
3. Heat source with fin heat sink resulted in 55% reduction in maximum temperature of a cabinet and there is continuous reduction in the temperature along length of fin
4. Temperature rise in a cabinet is found to be 3℃ which is well below the threshold limit
5. The analysis results obtained for Temperature rise and Inlet velocity satisfies the analytical calculation results
6. Results are also checked for mass balance and heat balance in a cabinet and hence satisfy
7. Present analysis helps engineers as a ready reckoner in decision making in provision to fins, on how to calculate air flow requirement and Temperature rise in a cabinet on both analytical basis and CFD

Present work is no more exhaustive, future work can be carried for different shapes and size of fins and using interrupted fins replacing continuous fins. Further optimization can be made by changing the fan location and size. Also present work can be experimentally compared for percentage variations in the obtained CFD results.

REFERENCES

[1]. Hoffman- A Pentair Company, "Heat dissipation in Electrical enclosure", "Technical information on Thermal Management of Electrical enclosures", ©2003 Hoffman Enclosures Inc.

[2]. Mahendra Wankhede, Vivek Khaire, Dr. Avijit Goswami and Prof. S. D. Mahajan, "Evaluation of cooling solutions for outdoor electronics", Journal on electronics cooling from electronics-cooling.com, Volume 16, No. 3, Fall 2010

[3]. Lakshminarasimha N, "Numerical Investigation of forced convection cooling of Electrical enclosure using CFD", Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 5, Issue 11, (Part - 5) November 2015, pp.62-66

[4]. Bud Industries, Inc., "Enclosure Design Tips Handbook", July 2007, © Bud Industries Inc.

[5]. ANSYS Fluent User Guide, Release 15.0, Nov. 2013 and ANSYS Fluent 12.0, Theory guide, April 2009

[6]. 2018, Flow rate conversion website, [Online], Available: http://www.traditionaloven.com/tutorials/flow-rate/convert-ft3-cubic-foot-per-minute-to-m3-cubic-meter-per-second.html

[7]. H K Versteeg and W Malalasekara, "Computational Fluid Dynamics- Finite Volume Method", Text book of CFD, edition 1995

[8]. Yunus A Cengel, "Heat Transfer- A Practical Approach", Cooling of Electronic Equipment, Chapter 15