Optimal Heat Sink Fin and Cold Lid Heights for Liquid Immersed Servers

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Abstract The system in this study is a closed server filled with Novac dielectric cooling liquid. The heat is generated by the CPU that conducts to the fin which helps to dissipate the heat. The heat convects via the dielectric liquid to the cold lid, where the cold lid is placed on the opposite side. The aim of this study is to find out the optimum value of the fin height and the cold lid height. A mesh accuracy investigation was conducted. The model set up in this work is validated with published experiment. An Optimal Latin Hypercube design (OLH) of experiment used to select 30 cases to be investigated. Genetic Algorithm (GA) was applied to find the optimum solution. A 3D model of COMSOL is used to find that the optimum fin height is 23.9 mm and the cold lid height is 30 mm. This dropped 22% of the temperature of the T_{case}.

Keywords: Fin height and lid height, Immersed server, Fin in enclosure, Conjugate heat, natural convection in rectangular enclosure.

1. Introduction

The wide spread of data centers in recent years resulted in increasing the demand on energy as well as generating more heat. Subsequently more efficient cooling methods are essential. Most data centers use air cooling technique, however liquid cooling techniques are very promising method which may have advantages for density cooling. The new technology brings water from the edge of the room to racks and other technology is bringing water into the rack. There are different solutions which bring the water into the rack or immersed the server in dielectric liquid.

The immersed server idea is that the server is immersed in dielectric liquid and the heat from The CPU convectes to the liquid then the heat is dissipated by cold lid in the opposite side. This study is about optimizing the heat transfer by looking at the heat sink fin height (H_{fin}) and the cold lid height (H_{lid}) as shown in Figure 1 .

As the liquid inside the server is closed. So, the heat transfer is done by natural convection where no pump or blowers are used. Val daiv [1] presented one of the early benchmark studies for heat transfer laminar flow in square enclosure where the left wall is cold and the right wall is hot. Tian [2] has done an experiment for the turbulent in square enclosure. In case of rectangular enclosure MacGregor [3] has investigated the fluid behavior in both cases laminar and turbulent for rectangular enclosure, and they found that in rectangular enclosure with aspect ratio between 1 and 40 and Prandtl number between 1 and 20 the fluid flow became a turbulent when $R_a>10^7$. For the heat source in enclosure Phan-Thien and Yang [4] numerically investigated vertical rectangular cavity with 3 heat source on lift wall and the other wall is cold. The study is to find out the optimum spacing between the heat sources. The optimum spacing arrangement can drop 10% of the temperature. Heat source in enclosure has been investigated in many studies [5-7]. However, finned enclosure was rarely studied experimentally or numerically. Nada [8] curried out experimental study on finned vertical rectangular enclosure. Horizontal Fins are on the hot wall side and the other wall is cold. The study investigated different Rayleigh number (R_a) and different fin length and fin spacing. He found that increasing the fin length increases the Nusselt Number and the effectiveness.

In the presented work the model of turbulent natural convection flow and conjugate heat transfer is used to investigate vertical sever filled with dielectric liquid. The CPU heat flux and cold lid temperature remain constant. An Optimal Latin Hypercube [9] design of experiment and Genetic Algrithm (GA) optimization method are used. The aim of this work is to find the optimum heat sink fin height and cold lid height.

2. Modeling methodology

2.1 Model geometry

The model consists of slice of a server with the dimensions 400mm x 4.5mm x Height of lid as a range between (30 – 45 mm). This is because the U1 (Industrial standard naming for server height) recommends it to be 45mm. the server was modeled in vertical position. The top and bottom wall assumed to be insulated. A 45mm x 45mm CPU (100W) was used on the bottom of the heat sink to generate heat. The temperature on the cold surface or cold lid is constant at 303.15 K.

Figure 1 illustrates the geometry of slice server. The heat sink fin is made of copper. the heat sink base area is 90mm x 90mm and fin thickness 1.5mm and the space between the fin 3mm [10]. All the dimensions were kept constant except the two parameters; heat sink fin height (H_{fin}) and cold lid height (H_{lid}).

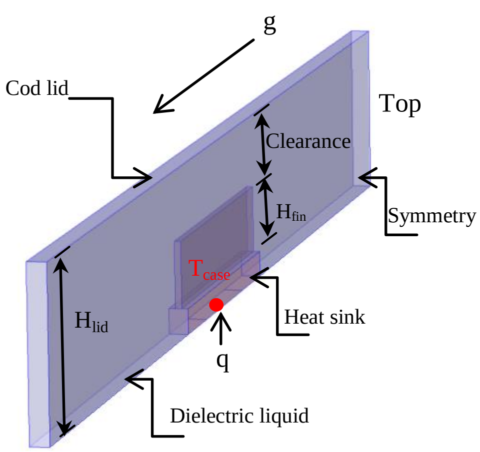

Figure 1: Model geometry

The side walls have symmetry boundary conditions. Using symmetry configuration reduces the computational domain and time.

2.2 Mathematical Model

The first step in solving the model is to determine whether the flow is turbulent or laminar. In case of natural convection the fluid situation can be determine by calculating R_a. As the heat is generated by heat flux the R_a is:

$$R_a = \frac{g\beta\Delta TL^4 q\rho^2 C_p}{k^2\mu} = 2.2x10^{11}$$

The Ra value of this case is greater than 10^7 so the flow is considered to be turbulent [11]. For the turbulent fluid flow in enclosure the most reliable and robust turbulent model is K-ϖ model as investigated in [12]. Therefore, this study used K-ϖ model.

The governing equations which represent the continuity, energy and momentum have been solved by COMSOL v4.3a.

2.3 Fluid and material properties

The material of heat sink is copper and the dielectric liquid is used as coolant liquid for the server is Novac which is made by M3 Company[13].

Table 1 present the thermal properties of the Novac liquid. The velocity is diminutive in fluid flow at natural convection, so the viscous dissipation can be neglected [14]. All the fluid thermal properties assumed to be constant except the density which is function of the temperature.

Table 1: Working fluid thermal properties

Properties	Abbrev.	Novac
Specific heat capacity	C_p	1140 (J/kg.K)
Thermal expansion	β	$1.151496x10^{-3}$ (K^{-1})
Dynamic viscosity	μ	$1.124782x10^{-3}$ (Pa.s)
Thermal conductivity	k	$6.9x10^{-2}$ (W/m.K)
Density	ρ	1716.2-2.2T (kg/m^3)

2.4 Mesh study

The mesh study was performed for the case of H_{fin}= 10mm and H_{lid}=38mm which is a point that was picked from design space distribution. The mesh consisting of 37563, 77977, 14586, 238149 and 465968 elements were used for the model simulation. The mesh accuracy depends on the temperature on the top center of the CPU which can be called T_{case}.

The mesh study shows that the maximum difference temperature for T_{case} is 0.1 K between the two grids 238149 and 465968 elements. Consequently, the grid 238149 elements are considered to be used in this study in order to save memory and computational time. The mesh study has been done to ensure that the mesh does not affect the results accuracy.

Wall-lifts-off may affect the accuracy of the results in turbulent model, so it needs to be checked as well. The recommended wall-lifts-off on most of the walls is 11.06 [15]. In this study the wall-lifts-off was found as 11.06 on all the walls as shown in Figure 2.

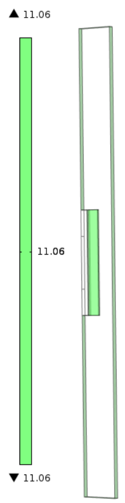

Figure 2. Wall-lift-off

2.5 Model validation

Before starting this study a validation has been carried out for previous published paper that mentioned in the introduction. Nada [8] has obtained empirical correlations for a horizontal finned vertical enclosure from the experiment which can be expressed:

$$N_u = 1.33 R_a^{0.56} \left(\frac{L}{H}\right)^{0.22} \left(0.022\left(\frac{S}{H}\right)^3 - 0.096\left(\frac{S}{H}\right)^2 + 0.131\left(\frac{S}{H}\right) - 0.044\right)$$

Where, Nu is Nusslet number, L is fin length, S is the space between the fins. To compare experiment work with numerical modeling, the dimensions and properties need to be the same. The dimensions are L/H=0.5 S/H=2 and the R_a vary from 150000 to 250000. The fluid behavior is turbulent the turbulent model used for this validation is K-ω model.

The Nusselt number for this study has been calculated by the below function.

$$N_u = \frac{hH}{K_f}$$

To know the Nusselt number the heat transfer coefficient is required to be calculated. The heat transfer coefficient comes from the heat transfer equation.

$$q = h(T_h - T_c) = -k\left(\frac{\partial T}{\partial x}\right)$$

$$h = \frac{-k\left(\frac{\partial T}{\partial x}\right)}{T_h - T_c}$$

Where the q is heat transfer in W/m^2 and h is the heat transfer coefficient. T_h is the temperature of the hot surface and T_c the cold lid temperature. The value of Nusselt number can be determined by using the below definition.

$$N_u = \frac{qH}{k(T_h - T_c)} = \frac{-\left(\frac{\partial T}{\partial x}\right)}{T_h - T_c}$$

Figure 3 show that the numerical model is in good agreement with experiment results. The average error between molding and experiment result doesn't exceed 5.4%. In this study this error can be considered as adequate for numerical and experiment the validation.

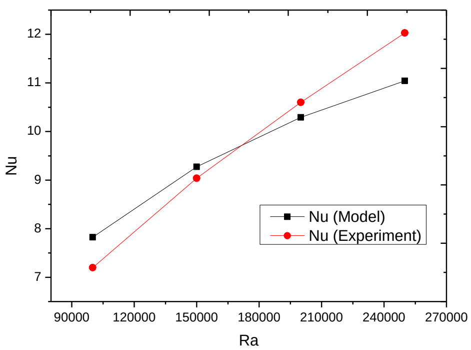

Figure 3. Nusselt number for experiment and the model

3. Result and discussion

The models were carried out to find out the optimum fin Height (H_{fin}) and cold lid height (H_{lid}) for the server. The H_{fin} varying from 9.5mm to 24mm and H_{lid} changing rang from 30mm to 44.5mm. Optimal Latin Hypercube design of experiment and GA optimization method are applied to create the distribution points and to find the optimum solution. The study is done by using COMSOL v4.3a for simulating conjugate heat transfer for natural convection turbulent model. The turbulent model used in this study is K-ω.

3.1 Temperature filed

To study how the temperature is affected in this paper, five cases were picked from thirty simulations. These five cases present the lowest T_{case} in this study.

Table 2: Lowest T_{case} cases

Case number	Fin height (mm)	lid height (mm)	Clearance parameter (mm)
1	21.5	40	3.5
2	22	30	2
3	22.5	44	9.5
4	23.5	33.5	4
5	23.9	30	0.1

The effect of heat sink fin height and cold lid height on the CPU temperature is presented in cut-line on the top of the CPU in Figure 4. As seen from this figure, the lowest T_{case} is case 5 which is the optimum solution that has the highest heat sink fin height which has bigger surface area too and lowest clearance parameter. It can be noticed that all cases were affected by the clearance between the fin height and lid height where lower clearance resulting in lower CPU temperature.

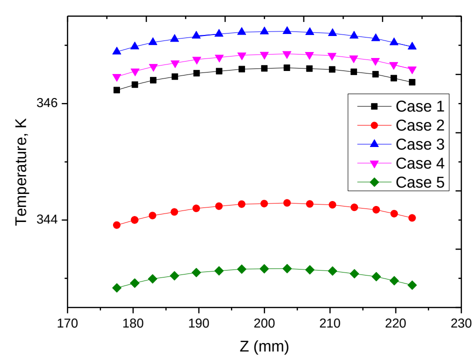

Figure 4. Temperature line along the top centre of the CPU in z direction

3.2 Optimization methods and analyses

In optimization problem, the best response surface is selected form design space that created by design variables. The selection points in design space are important to provide accurate response surface which known as design of experiment (DoE).

The study has been carried out to determine the effect of two design variables; heat sink fin height and cold lid height to minimize the T_{case}.

An optimum Latin Hypercube [9] Design of experiment (DoE) is performed to create 30 combination of two design variables. The upper and lower limits of the two design variables is illustrated in Table 3.The uniform distribution of the design space is shown in Figure **5**.

Table 3: Design variables upper and lower limits

Variables	Upper (mm)	Lower (mm)
Fin height	9.5	24
Cold lid Height	30	44.5

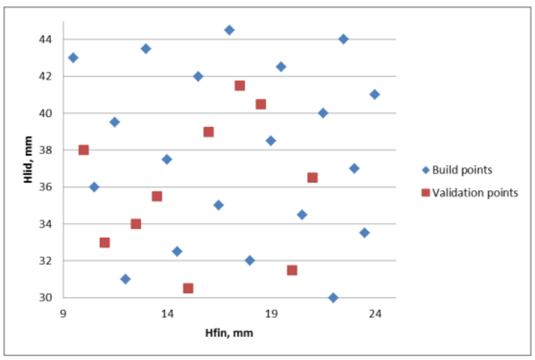

Figure 5. Design of experiment

COMSOL software is used to run 30 models that represent the selected 30 points uniform distribution in the design space. The approximation response surface of CPU top center temperature T_{case} within the design space was performed by applying Least Squares Regression approximation method. The approximation of T_{case} for fin height and cold lid height is shown in Figure **6**.

The analysis of the thirty solutions presented that the fin height influence the T_{case} much more than cold lid height. T_{case} drop dramatically with increasing of fin height. However, the T_{case} has different behavior with variation of cold lid height. Figure **6** show also that the lowest T_{case} at the highest limit of fin height which is 23.9 mm with lowest cold lid height 30mm. The GA optimization technique is applied using Hyperstudy v11 of Altiar package. Table 4 compares between the predicted T_{case} and simulated T_{case} with accepted error. Also this table shows the lowest T_{case} that come from the optimum design variable.

Table 4: Compare between the predicted T_{case} and simulated optimum design variables.

Design variabels (mm)		T_{case} (K)		
Fin height	Cold lid heigh	predicted	Simulated	Error %
23.9	30	342.3	343.15	0.25

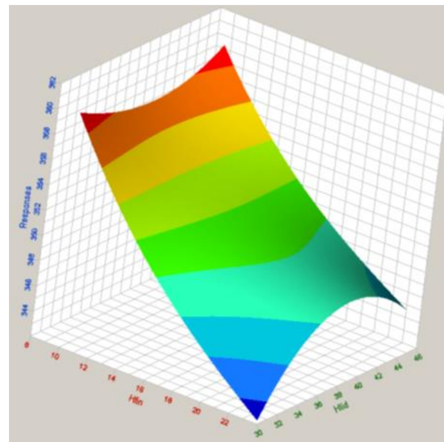

Figure 6. Response surface of T_{case}

4. Conclusions

This study has been done for fin heat sink immersed in Novac liquid in a server. Natural convection conjugate heats for vertical sever is solved using COMSOL v4.3a. Since the $R_a>10^7$ in the server the fluid solved as turbulent flow and the turbulent model that used to solve the model is K-ω. Mesh independency investigation was conducted to ensure that it does not affect the solution accuracy. The model set up was compared with previous published experimental results and showed that the model in this study is in good agreement with previous experimental work.

An optimal Latin Hypercube design of experiment created thirty points in design of space for two design variables which are heat sink fin height and cold lid height. Genetic

Algorithm is used to obtain an optimum value of two parameters from thirty simulations.

Five out of thirty cases were selected to show the effect of the changing parameters on temperature. These five cases represent the lowest T_{case} of thirty cases. The heat sink fin height has big influence on decreasing the T_{case}. The cold lid height helps to reduce the T_{case} once it became close to the fin.

The optimum fin height is 23.9 mm and the cold lid height is 30 mm. The value of T_{case} for this optimum solution is 343.16 K. This dropped the temperature of the T_{case} 22% compare to highest T_{case} of the thirty simulations that are performed in this study.

5. References

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