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Pin-Kanatçık, Plaka-Kanatçık ve Plaka-Pin-Kanatçıkların Soğutma Performanslarının Sayısal Metod Kullanılarak Karşılaştırılması

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MAKALE BİLGİSİ

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ÖZET

Elektronik ekipmanların soğutulması alanında ısı transferinin geliştirilmesi mühendislik çalışmalarını gerektirmektedir. Bu gelişmeler doğrultusunda ekipmanın performansını ve güvenilirliğini sağlamak için termal yönetim stratejilerine ihtiyaç duyulmaktadır. Genel olarak, elektronik ekipman soğutması için ısı alıcısı geometrilerinden iki türü kullanılır. Bunlar, plaka-kanatçık ısı alıcıları ve pin-kanatçık ısı alıcılarıdır. Kullanım alanına bağlı olarak, kanatçık tiplerinin birbirine üstünlüğü vardır. Bununla birlikte, plaka-pin-kanatçık ısı alıcıda bir araya getirilerek uygun bir geometri tasarlamak mümkündür. Isı alıcısının soğutma performansı farklı kanatçık türleri için, çalışmada hesaplamalı akışkanlar dinamiği yazılımı Fluent kullanılarak birbirleriyle karşılaştırılmıştır. Aynı yüzey alanına sahip ısı alıcıları her durum için modellenmiştir. 1000 W · mm^{-2} ısı akısı 104 mm x 104 mm plaka yüzey alanı üzerine tanımlanmıştır ve ısı alıcıları için kanatçık olarak kullanılan pinlerin çapı ve plakaların genişliği 4,06 mm'dir. Isı alıcılarının soğutma performanslarının karşılaştırılmasında kullanılan sıcaklık dağılımı eş eğrileri ve akış hızları elde edilmiştir. Isı alıcılarının sıcaklığı 45 ^{o}C'nin altında kalmıştır. Yalnızca pin kanatçık ısı alıcı soğutma performansının, yalnızca plaka ve plaka-pin kanatçık ısı alıcılarından daha iyi olduğu söylenebilir.

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Comparison Of Cooling Performances Of Pin-Fin, Plate-Fin And Plate-Pin-Fin By Using Numerical Method

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ABSTRACT

The improvement of heat transfer has necessitated engineering work in the field of electronic devices cooling. In order to achieve device performance and reliability in the direction of these improvements, there is a need of thermal management strategies. Generally, two types of heat sink geometries are used for electronic equipment cooling. These are plate-fin heat sinks and pin-fin heat sinks. Depending on the area of use, the pin types have superiority to each other. However, it is possible to design a suitable geometry can be combined. The cooling performances of heat sinks for different fin types are compared with each other with the Fluent, computational fluid dynamics software, in the study. The heat sinks have the same surface area are modelled for all cases. The heat flux 1000 W · mm^{-2} is defined on 104 mm x 104 mm plate surface and the diameter of pins and width of plates used as fin are 4.06 mm for heat sinks. Temperature distribution contours and flow velocities used for comparison of cooling performances of heat sinks are obtained. The temperature of heat sinks stays under 45 ^{o}C. It can be said that only plate-fin heat sinks cooling performance is better than plate-pin-fin and pin-fin heat sinks.

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1. INTRODUCTION *(GİRİŞ)*

The heat convection mechanism, a mode of heat transfer related to fluid movement, involves both the transfer of heat through the interaction of molecules in the fluid and the transfer of energy due to the movement of the fluid. In natural convection, the fluid is not moved by an external energy source, and the result of the fluid density change is the result of the lifting or lowering force acting on the fluid. The fluid with increased temperature moves upward, while the fluid with lower temperature moves downward. It is the internal forces acting on the fluid which have density differences within the molecular motion. This net effect, which creates natural convection around the surface, is called lift force. If assessed within the internal force, it is related to gravitational force and is proportional to density [1]. Flow rates in natural convection are generally much smaller than in forced convection, so heat transfer by natural convection is also slower. In many applications where heat transfer occurs in different ways, natural convection plays an important role in the design or performance of the system. Moreover, natural convection is often preferred when it comes to reducing the complexity and number of elements in cooling systems and also minimizing operational costs [2].

Numerical analysis is one of the indispensable elements of today and its importance is increasing day by day. One of the most important problems faced by scientists is to solve them after they express their problems mathematically. At this point numerical analysis becomes a requirement to solve problems. Already, as mathematics has developed over the years, numerical analysis methods have emerged as a branch of mathematics and developed. Especially the emergence of computers, the widespread use and the increase in capacities have increased the importance of these techniques. In engineering applications, there are many problems involving heat transfer between the fluid in a closed environment and the surfaces at different temperatures of the domain [3].

Since the equations expressing natural convection are nonlinear equations, two or three dimensional analytical solutions have not yet been made. Numerical solutions of these equations are used extensively under certain approach methods and boundary conditions [1].

Heat sink is the thermal management equipment which is commonly used in electronic device cooling. Generally, two types of heat sink geometries are used for cooling [4-8]. These are plate-fin heat sinks and pin-fin heat sinks. Depending on the area of use, the pin types have superiority to each other [4,9]. However, two types of geometric features that provide increased efficiency fin. Plate-pin-fin heat sink, it is possible to design a suitable geometry can be combined [10-13].

There are some studies for comparison pin-fin heat sinks with plate-fin heat sinks. When these studies are examined. Joo and Kim make numerical and experimental studies on comparison cooling performances of plate fin heat sinks and pin fin heat sinks. Fluent software is used for numerical analysis. Numerical and experimental results are obtained similar [9]. Sparrow and Vemuri make the comparison of optimum pin-fin heat sink with plate fin heat sink at the same surface area. Results show that pin-fin heat sinks have forty percent less thermal resistance than plate-fin heat sink [4].

In last decade, there are studies on plate-pin fin heat sinks and comparison with the other traditional two types of heat sinks. Yuan et al. employee Fluent, Computational Fluid Dynamics (CFD) software, to asses the plate-pin fin heat sinks' potential in electronics cooling [10]. Zhou and Cotton study on investigation of hydraulic and thermal performance of plate-pin fin heat sinks have different pin geometries numerically. CFX software, based on Reynolds-Averaged Navier-Stokes (RANS) equations, is used for solution with Finite Volume Method. The prediction of heat transfer and turbulent flow through the channels of heat sink is made with a k-w based Shear Stress Transport (SST) model [11].Yu et al. performs numerical simulations to compare thermal performances of plate fin heat sinks and plate-pin fin heat sinks. Plate-pin fin heat sinks reduce thermal resistance and achieve better air-cooling results, but there is difference in surface areas of heat sinks [12]. Yang et al. carry out numerical analysis of the plate-circular pin fin heat sink. Finite difference method is used with adopting a control volume. The result as plate-circular pin fin heat sink has better cooling performance than the plate fin heat sink [13].

In this study, the fin types of heat sinks are compared with each other for natural convection using the Fluent. SST turbulence model is used. Pin fins are added between plate fins, so surface areas of compared heat sinks are not the same in other studies [10-13]. As a novelty, surface areas of the plate-pin fin heat sinks and other traditional types of heat sinks are modelled at the same value and cooling performance comparisons are made for pin, plate and plate-pin fin heat sinks.

2. METHODS *(YÖNTEM)*

2.1. Simulation Steps *(Benzetim Adımları)*

Simulations are performed in CFD software Fluent. The steps followed in the study are described below.

• The geometries to be used are created in the 'Geometry' module of the Fluent software and the necessary surface designations are made.

• The mesh structure specified for the model is created in the 'Mesh' module of the Fluent software.

• Boundary conditions to be used are specified in the 'Setup' module of the Fluent software. Initial conditions are set and then iterated.

• In the 'Solution' module of the Fluent software the solution is converged and complete, after that the 'Results' module is used to obtain the results.

Some assumptions are made in the model solution. These are:

• Flow is solved in three dimensions and turbulence.

• Newtonian flow is accepted.

• Gravitational acceleration is -9.81m · s^{-2} at y axis.

• Steady-State solutions are available.

• SST turbulence model is used for solution.

2.2. Geometry and Mesh Structure *(Geometri ve Ağ Yapısı)*

In this study, heat sinks have different geometrical structures are compared for cooling performances. Heat sinks are placed perpendicular to base of the domain. A basic type of a heat sink and its geometrical parameters are shown in Figure 1.

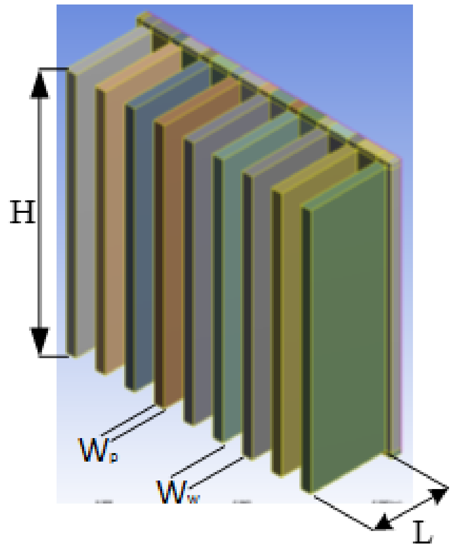


Figure 1. Geometrical parameters of heat sink *(Isı alıcının geometrik parametreleri)*

H is the length of plate in y direction, L is the length of fins in z direction which is 30.94 mm, W_p is the width of plate fins and this length is equal to the diameter of pin fins. W_w is the distance between fins which is 7.93 mm, also it is the same for plate and pin fins. The surface area of heat sinks are modelled the same. It is assumed that W_p = D (Diameter of pin fin) and L is equal for all cases.

W_p = D = 4.06 mm and H = 98 mm for all cases, from Equation 1, n=16. The solution domain includes the heat sink and air around heat sink. The domain size is modeled five times in x dimension, seven times in y dimension and ten times in z direction of heat sink edges. The reference of domain size is the study of Joo and Kim [9]. Figure 2 shows the geometrical and mesh structure of solution domain.

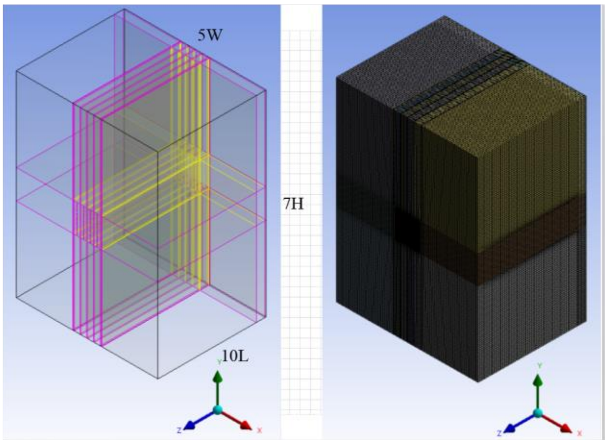
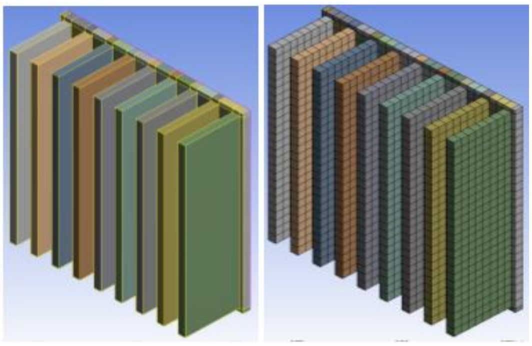
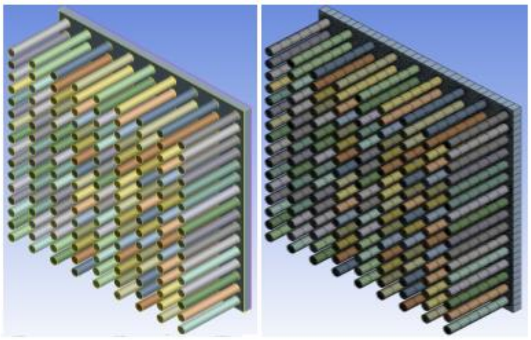


Figure 2. Geometrical and Mesh Structure of Solution Domain *(Çözüm Alanının Geometri ve Ağ Yapısı)*

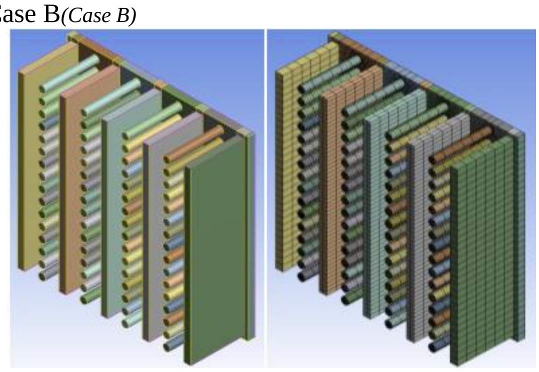
Heat sink modelled in Case A has only have plate fins, Case B only has pin fins, Case C and Case D have plate-pin fins. Geometrical and structures of cases are shown in Figure 3.



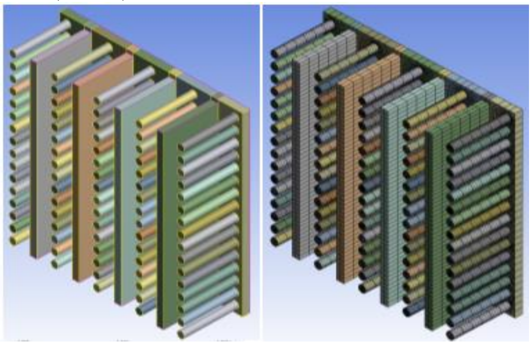
Case A*(Case A)*



Case B*(Case B)*



Case C*(Case C)*



Case D*(Case D)*

Figure 3. Geometrical and Mesh Structure of Heat Sinks *(Isı alıcıların geometrik ve ağ yapısı)*

Table 1 shows the mesh statistic of cases. Below the mesh skewness value of 0.23, the mesh quality is better [14].

Table 1. Mesh statistics of cases *(Durumların ağ istatistikleri)*

Case	Nodes	Elements	Mesh Skewness		
			Min	Max	Average
A	2027776	1978152	1.3e-10	3.2e-3	1.9e-5
B	1978778	1937628	1.3e-10	0.95	0.15
C	1449947	1417548	1.7e-6	0.94	0.15
D	1591116	1564596	1.7e-6	0.94	0.129

2.3. Solver (*Çözücü*)

Numerical simulation is made with RANS based Fluent software. The equations used from solver while iterations are show below [14].

Continuity Equation:

$$\frac{\partial \rho u_i}{\partial x_i} = 0 \tag{2}$$

Momentum Equation:

$$\rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \tag{3}$$

Energy Equation:

$$\rho u_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\frac{\mu_L}{\sigma_L} + \frac{\mu_t}{\sigma_t}\right)\frac{\partial T}{\partial x_j}\right] \tag{4}$$

Boundary conditions are determined before solution. The base plate surface of heat sink is wall with heat flux value of 1000 W · mm^{-2}, The surface around heat sink base plate surface is symmetry. All other side walls of solution domain are chosen as wall at 300 K. Solution is made as Steady-State. Gravitational acceleration is inserted as 9.81 m · s^{-2} in negative y direction. SST model is chosen for solution with Pressure Implicit Splitting Operator (PISO) algorithm. Turbulence solver includes laminar equations already. Spatial discretization of pressure is chosen as body force weighted in solution methods. Material of heat sink is aluminum. The fluid around heat sink is air. Initial properties of air and aluminum before solution are obtained from Fluent database. The properties of materials used in simulation are shown in Table 2.

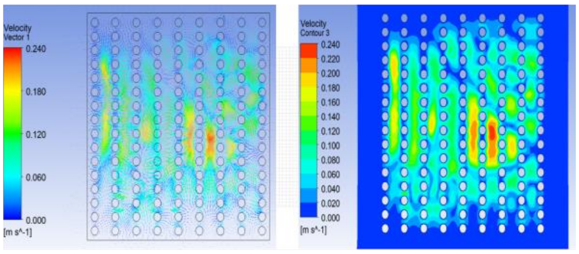
Table 2. Properties of air and aluminum *(Hava ve alüminyumun özellikleri)*

	Air	Aluminum
Density (kg · m^{-3})	1.225	2719
Specific Heat (J · kg-1 · K^{-1})	1006.43	871
Thermal Conductivity (W · m^{-1} · K^{-1})	0.0242	202.4
Viscosity (kg · m^{-1} · s^{-1})	1.7894e-5	

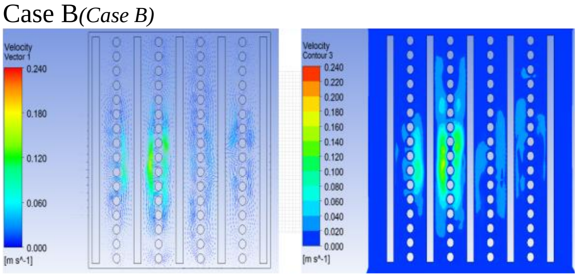
3. FINDINGS *(BULGULAR)*

The results as air velocities, temperature contours of heat sinks, temperature contour of heat sinks' base plate surfaces are obtained from simulation. These results are used for comparison of heat sinks cooling performances in cases.

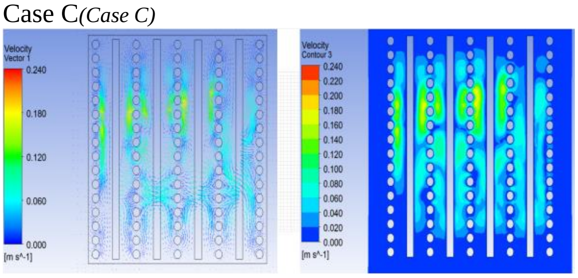
The most cooled heat sink must have the fastest air velocity in simulation. Air flow velocities have higher values at the middle of the geometries. This result can be explained with higher temperature occurring at the middle than other areas.



Case B*(Case B)*



Case C*(Case C)*



Case D*(Case D)*

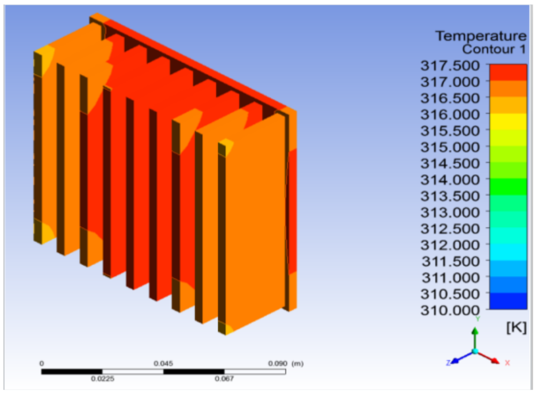
Figure 4. Velocity Vectors and Contours of Cases Distance 24 mm from Heat Sink Base Plate Surface

(Isı alıcının taban yüzeyinden 24 mm uzaktaki bir yüzeyde durumların hız vektörleri ve eşeğrileri)

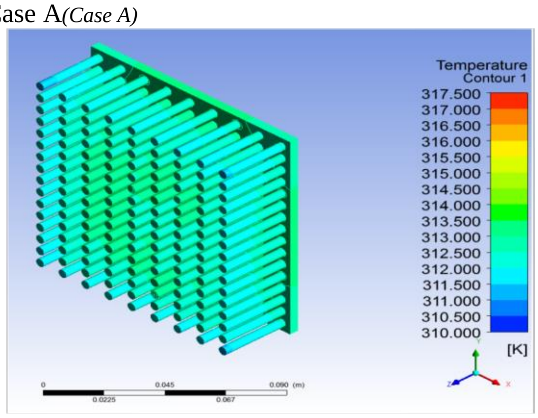
Figure 4 shows the velocity vectors and contours of heat sinks. The sampling plane is placed 24mm distance from heat sink base plate surface in XY axis. This plane is placed near of the half of the height of fins. In the Figure 4 Case B has the fastest air movement, Case C has the slowest air movement. Velocity of cases are shown in figure between 0 to 0.24 $m \cdot s^{-1}$. The red colored areas represent the biggest velocity values; the dark blue colored areas represent zero velocity. The velocities are increasing when closing the center of the geometry.

Heat is transferred from heat sink with air. Air must move, so air must have velocity to be an actor in convection. It can be said that increasing in air velocity means increase in heat transfer.

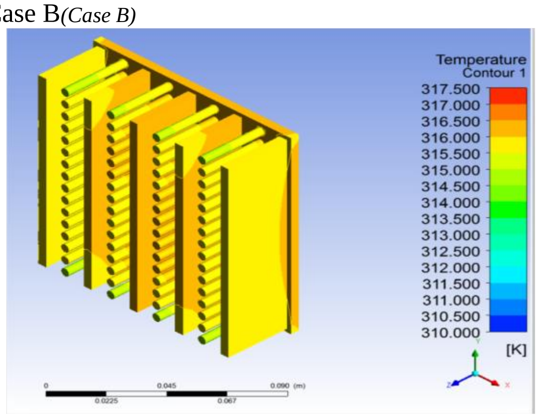
Temperature contours of surface areas of the heat sinks are shown in Figure 5. Temperature values of heat sink surfaces in contours between 310 K to 317.5 K. The best cooling performance can be seen at full of pin structure in Case B, the worst performance can be seen at full of plate fin structure in Case A. Cooling performance of Case D is better than Case C which are plate-pin fin heat sinks.



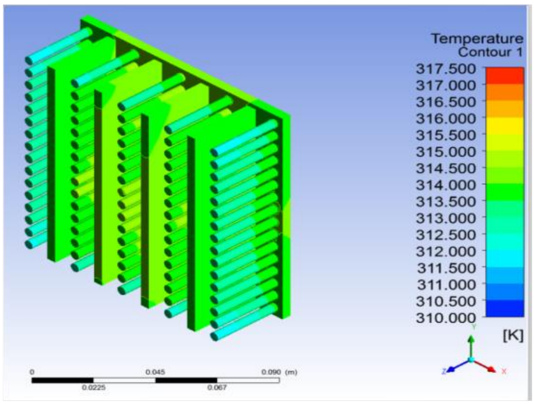
Case A*(Case A)*



Case B*(Case B)*



Case C*(Case C)*



Case D*(Case D)*

Figure 5. Temperature Contours of Cases *(Durumların sıcaklık eşeğrileri)*

Figure 6 shows the volume average temperature of heat sinks surface vs number of pins curve for cases. Increasing in fin numbers cause decrease in volume average temperature.

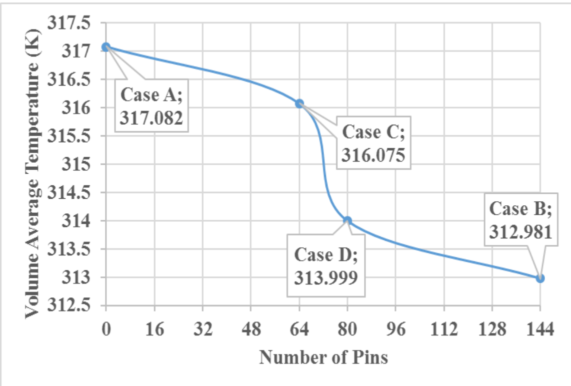
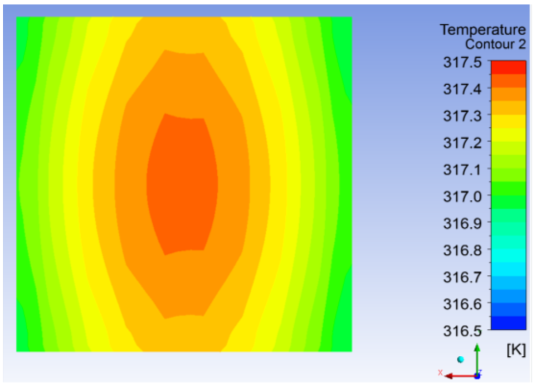
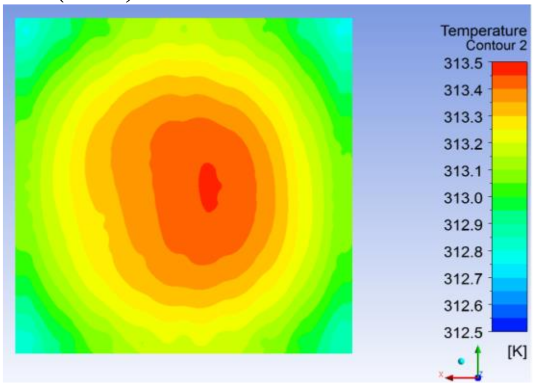


Figure 6. Volume Average Temperature of Heat Sinks of Cases *(Durumlardaki ısı alıcıların hacimsel ortalama sıcaklığı)*

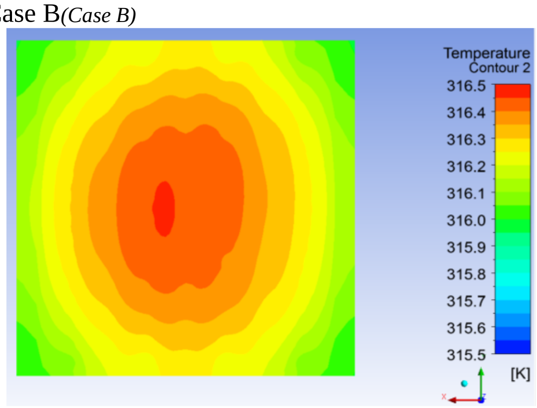
Figure 7 shows the Temperature contours of heat sinks base plate surface. The comparison of cooling performances of heat sinks is directly about base plate surface temperature because electronic equipment is connected on this area. Temperature values are between 316.5 K - 317.5 K for Case A; 312.5 K -313.5 K for Case B; 315.5 K - 316.5 K for Case C; 313.5 - 314.5 K for Case D.



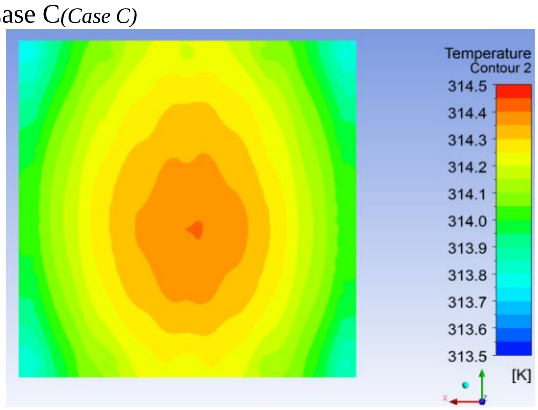
Case A*(Case A)*



Case B*(Case B)*



Case C*(Case C)*



Case D*(Case D)*

Figure 7. Heat Sink Base Plate Surface Temperature Contours of Cases *(Durumlardaki ısı alıcıların taban alanlarının sıcaklık eşeğrileri)*

Figure 8 shows the area average temperature of base plate surface vs number of pins curve for cases. Increasing in fin numbers cause decrease in area average temperature.

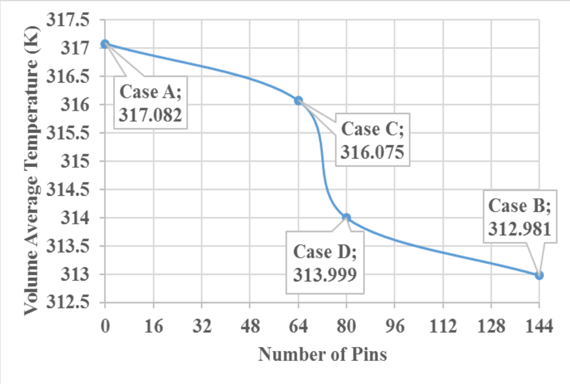


Figure 8. Area Average Temperature of Base Plate Surface (Heated Surface) *(Taban alanı ortalama sıcaklığı (Isıntılan yüzey))*

Figure 5 and Figure 7 shows that the heights temperatures are occurring at the middle of the structures as surfaces of heat sinks fins and base plate surfaces of heat sinks. This situation explains the higher air velocities near of center in Figure 4. The temperature curve in Figure 8 is similar with the curve in Figure 6, so it can be seen that there is a reliable results of temperatures, which validate each other with curves.

Aforementioned study can't be referenced from other plate-pin fin comparison studies because in these studies, cooling performance is increased by adding pin fins between plate fins, so surface areas of compared heat sinks are not the same in other studies [10-13].

The results show that pin-fin heat sinks have less thermal resistance than plate-fin heat sink as it is mentioned in [4].

4. CONCLUSION AND DISCUSSION *(SONUÇLAR VE TARTIŞMA)*

In this study, simulation results show that temperature of all types of heat sinks modelled are under 45 ^{o}C. This temperature is in reliable range for electronic equipment.

The more of pins in heat sinks as fins means increasing in cooling performance. The air velocities are highest at Case B. Air velocities at Case C is higher than Case B. The Average temperatures is heights at Case A and lowest at Case B. Average temperatures of Case C is lower than Case C. Number of pins in structures causes this difference.

The superiority of plate fins used in heat sink is known as giving a path for flow for better convection with faster air flow, but this superiority doesn't work in natural convection, at lower fluid velocities than fluid velocities in forced convection.

Increase in pin number means increase in cooling performances of heat sinks. The pins let the air flow between them and this situation explains the better cooling performance. Comparison results show that only plate-fin heat sinks cooling performance is better than plate-pin-fin and only plate-fin heat sinks for natural convection.

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