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Ladder Heat Sink Design Using Adaptive Neuro- Fuzzy Inference System (ANFIS)

Ahmad Bataineh*, Wafa Batayneh, Ahmad Al-Smadi, Baian Bataineh

Mechanical Eng. Department, Jordan University of Science and Technology, Irbid, 22110 Jordan.

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Abstract

Last decade witnessed a significant research effort directed towards heat sink design to improve its performance. Conventional heat sinks consist of parallel plates or pin fins. Ladder heat sink design is one of the effective recent designs formed by inserting a link between two parallel plates. In this work, the performance of ladder heat sink design is studied and compared with two designs, namely; elliptical and parallel plate heat sink designs. A computational simulation of the heat sink designs carried away using COMSOL Multiphysics software. Adaptive Neuro Fuzzy Inference System (ANFIS) is used to predict the pressure drop value with changing the dimensions of the heat sink fins, namely; length, width and height, and comparing the results with COMSOL values. Results show that ladder heat sink design has better performance in comparison with the other heat sink designs according to many parameters used to characterize the performance of the heat sink design, namely; pressure drop, temperature, cooling power and fluid velocity. Also, ANFIS shows accurate results in predicting the pressure drop value compared with the accurate value obtained from COMSOL Multiphysics.

Keywords: Heat sinks; Ladder heat sink; ANFIS; Heat transfer in electronics; Thermal heat management; CPU;

1. Introduction

Cooling of electronic devices is a significant mechanism that restricts the performance of these devices. With the increasing demand of the supercomputing, gaming, other heavy-duty activities on the electronic devices, computers, and laptops, the heat generation inside these devices becomes a considerable issue that may damage internal electronic components of these devices. A better thermal management is required to enhance and accelerate the removal of the generated heat inside the electronic devices. The installation of heat sink components improves the removal of the generated heat. These integrated metal components dissipate the heat generated from the electronic chips (e.g. Central Processing Unit "CPU") to the surroundings, outside the electronic device. Heat sinks design consists of fins, which are thin objects made of metal connected with the heat source to increase the dissipation heat power, to increase the heat transfer surface area, and to enhance the heat dissipation from the electronic device out to the surrounding.

To improve the heat transfer removal from the electronic components, several designs of heat sink have been developed since 1980[1]. *Wang et al.,* 2009 [2] investigated the thermal resistance of a heat sink with horizontal embedded heat pipes. This heat sink model consists of a base plate and heat pipes which are integrated to the CPU surface to dissipate the generated heat from the CPU. They concluded that the total thermal resistance of this heat sink type is mainly a function of heat pipes quality, which controls the base plate resistance. Choi et al., 2012 [3] proposed another CPU cooler to enhance the heat dissipation without adding another heat pipes, with a low noise level fan under the confined space constraints of a computer chassis. They used computational fluid dynamics (CFD) simulations to optimize their design by enhancing the cooling capacity, confined size, reduce the cost, and maintain low-noise level. Brinda et al., 2012 [4] proposed a ladder heat sink model, which simply represents a link that connects between two parallel plates. They found that the dissipated heat of the ladder model is a function of the pressure drop and thermal resistance values.

Different studies done regarding the optimization of microchannel heat sinks, in terms of the thermal management enhancement. Wang et al., 2009 [2] developed an optimized pin fin heat sink model, in terms of the dynamic response and pressure drop, using a genetic algorithm. This algorithm is a strong method for global search and design optimization of pin-fin heat sinks. Kim et al., 2009 [5] built a heat sink model using volume averaging theory to optimize the heat sink design of connected fins via branches. These branches were placed in normal direction to the cooling fluid flow, to maintain the maximum exposure between the fluid flow and the heat sink surface area. Using the branched fins in water

* Corresponding author e-mail: ambataineh2@just.edu.jo.

flow media, allows thermal resistance to reduce by 30% compared to heat sinks with integrated rectangular fins. The value of the thermal resistance reduction varies based on the pumping power of the cooling fluid and the length of the heat sink.

Recently, researchers aim to use Artificial Intelligence technologies in heat sinks designs. Chou et al., 2009 [6] employed a grey-based fuzzy algorithm with the orthogonal arrays to investigate the optimal designing parameters, for a parallel-plain fin heat sink under multiple thermal characteristics. The variable thermal performance conditions are evaluated by obtaining a grey–fuzzy reasoning grade. The evaluation of the extracted data is done based on the grey relational coefficient of each performance characteristic. The study concluded that the gap between the fins, the height of fin and the air speed are dominant design parameters, which controls the thermal performance of the heat sink. Batayneh et al., 2013 [7] designed a neural network model of a parallel-plain fin heat sink based on experimental results, which have been obtained from a previous study[8]. They constructed and analyzed a quadratic model equation of the affecting parameters using Response Surface Methodology for determining the important factors affecting the performance of the heat sink, and the quadratic effect of every factor by using design of experiment analysis of variance and regression analysis. Their results showed that neural network model has a maximum error of less than 13.54% compared with the experimental results.

The major focus of this research is predicting different parameters with different geometry dimensions for heat sink model using Adaptive Neuro Fuzzy Inference System (ANFIS). The training data used was obtained from simulating heat sink model using COMSOL Multiphysics software. ANFIS is a powerful tool used widely for modeling and predicting related data for various models in heat transfer applications. For example, heat transfer in an air-cooled heat exchanger equipped with classic twisted tape inserts, free convection heat transfers from a vertical array of attached cylinders and the effect of critical parameters on the heat transfer coefficient of nanoparticles-TO based nanofluid [9-13].

Mehrabi and Pesteei provided a model for convection heat transfer of turbulent supercritical carbon dioxide flow in a vertical circular tube for the empirical results obtained by Kim et al. [14]. In addition, they studied helicoidally double-pipe heat exchangers, used experimental results for training and test data using ANFIS and compared the results using statistical criterions (R2 and RMSE) with empirical ones. Their results suggest that the proposed ANFIS model is valid and expandable [15, 16].

Other studies also compared experimental data with ANFIS model. Salehi et al. performed six different volume fractions of Al2O3 nanoparticles in distilled water. Then, they compare the actual nanofluid Nusslet number with the prediction of the ANFIS model; the results suggest a degree of agreement between experimental observations and numerically calculated values, to be greater than 0.99 for all cases. [17, 18].

The rest of this paper is organized as follows: section 2 discusses the methodology used to estimate the performance of the different types of heat sinks, including the structure of the different types of heat sinks (elliptical, parallel-plate and ladder), equations and boundary conditions that will be used in the simulation. Section 3 discusses the usage of ANFIS for predicting the pressure drop value of ladder heat sink design for a range of inputs. Section 4 presents the results obtained from the simulation of the different heat sink designs, a comparison between the performances of the proposed designs and the results of predicting the pressure drop value using ANFIS. Finally, concluding remarks are presented in section 5.

2. Structure, Methodology, Assumptions and Boundary Conditions

The model domain is represented by a rectangular prism. Its length, width and height dimensions are $10cm$, $3.125cm$, and 4.5 cm respectively, as shown in Figure 1. The heat source is a square which has a length of 2.5 cm and placed at the bottom of the domain. The heat sink fins are integrated on the top of the heat source. The cooling fluid is pumped from the inlet, as shown in Error! Reference source not found., flows through the fins channel and exits at the far end outlet of the domain. The cooling fluid absorbs the generated heat from the heat source during passes through the fin's channels. In this study, three different heat sink designs are considered; the elliptic, parallel plate, and the ladder designs, each has 5 fins. The elliptic heat sink geometry model is shown in Error! Reference source not found.**.** The elliptic fin cross sections are formed by minor and major axes, which are of $1\ mm$ and $20\ mm$ respectively. Error! Reference source not found. illustrates the parallel plate heat sink geometry, which has a length and width of 20 mm and 1 mm respectively.

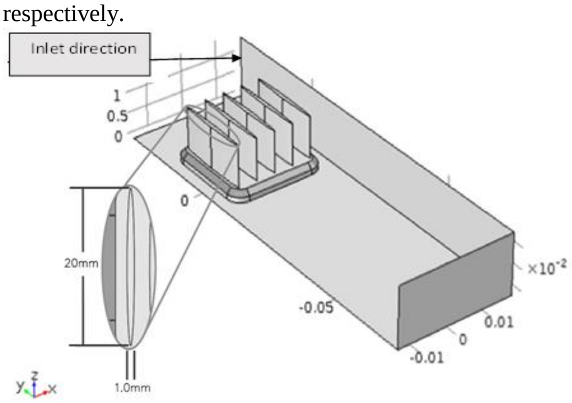

Figure 1. Elliptic heat sink design

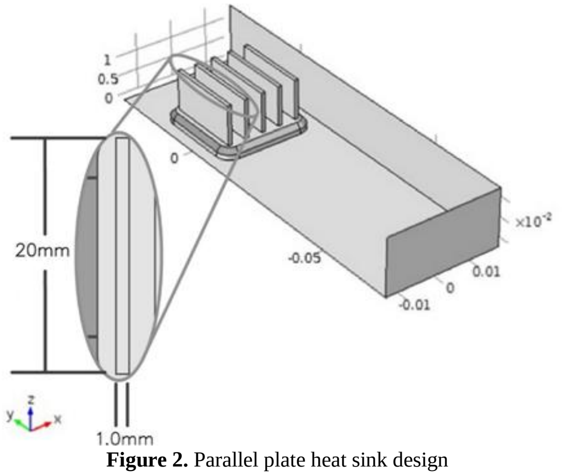

Figure 2. Parallel plate heat sink design

The ladder heat sink design is formed by removing a section of 3 mm length at the middle of each rectangular plate fin [4]. The proposed section removal is done only on the 2nd and 4th fins as shown in Figure 3.

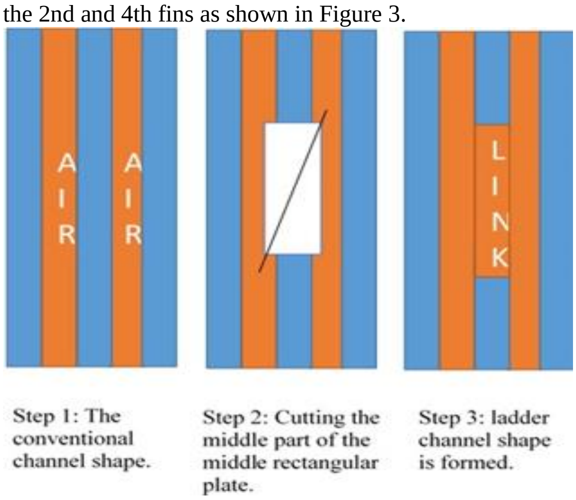

Figure 3 . steps of forming the ladder channel shape

Figure 4 shows the ladder heat sink geometry and the final simulation domain. This removed section will increase the turbulence in the cooling fluid flow and enhance the heat removal from the heat sink fins.

Parallel plate heat sink designs are widely used in electronics cooling applications since 1980 [1], and it was proved that it is effective economically [23]. Therefore, since the proposed ladder heat sink design consists of rectangular plates put in certain pattern as illustrated in Figure (3), similar design process of parallel plate heat sink can be followed.

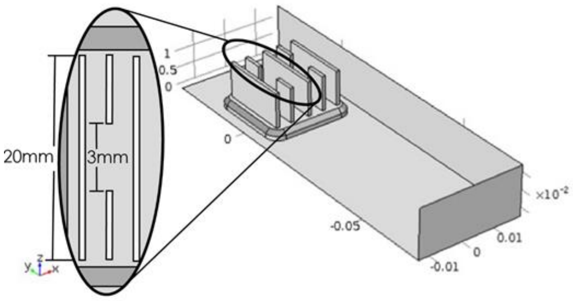

Figure 4 : Simulation environment of studying the performance of one link ladder heat sink design

Similar way followed to make the ladder heat sink design with one link can be also applied to form two and three links ladder heat sink design as shown in Figure 5 and Figure 6.

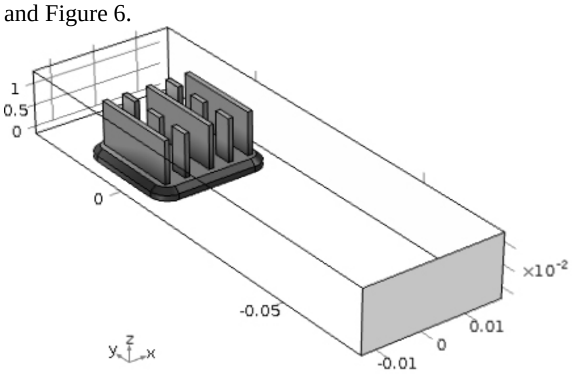

Figure 5 . Simulation environment of studying the performance of two links ladder heat sink design

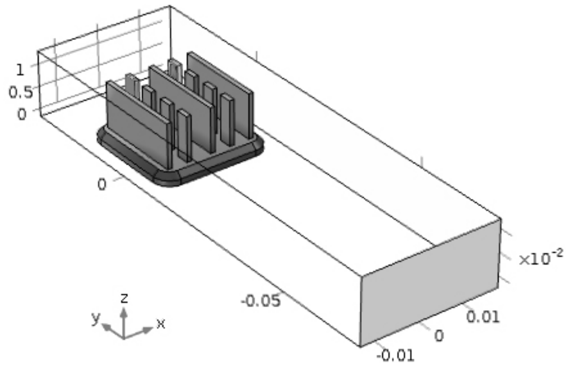

Figure 6 . Simulation environment of studying the performance of three link ladder heat sink design

2.1. Mathematical formulation

The heat transfer modes in the domain are conduction heat transfer from the heat source to the heat sinks' fins, and heat convection from the heat sink fins to the cooling fluid. COMSOL Multiphysics provides Conjugate Heat Transfer module to simulate a combination of conduction and convection heat transfer modes. The governing equations of such physical problems are represented by the mass conservation (continuity), **Eqn. 1**, and Naiver-Stokes momentum equation, **Eqn. 2 [22]**. We assume steady laminar flow with incompressible working fluid properties. The governing equations are given as following:

$$\rho\vec{\nabla}.\vec{u} = 0 \tag{1}$$

$$\rho(\vec{u}.\vec{\nabla})\vec{u} = \vec{\nabla}.[-p + \mu(\nabla\vec{u} + (\nabla\vec{u})^T)] + \vec{F} \tag{2}$$

Where $\rho\ (kg/m^3)$ is the cooling fluid density, $u\ (m/s)$ is cooling fluid velocity, $\mu\ (Pa.s)$ represents the dynamic viscosity, $p\ (Pa)$ is the pressure inside the channel flow domain, $F\ (N)$ denotes the sum of all volumetric forces, which equals to the gravitational force coefficient, $\vec{g}\ (m/s^2)$, in this simulation model. There are three unknown field variables (dependent variables): The velocity field components, U, the pressure, P and the temperature, T.

2.2. Boundary Conditions:

The boundary conditions of the velocity and temperature at the inlet are respectively $1\ m/s$ and$22°C$. Also, the boundary condition of the pressure at the outlet is set to zero.

Boundary conditions should be identified based on the model selected, in our case: Conjugate heat transfer module. There are default boundary conditions with the physics and other boundary conditioned selected by the user.

Firstly, the default boundary conditions of heat transfer in solids are as the following:

Heat transfer in solids boundary condition:

The Heat Transfer in Solids boundary condition selects the domain that will define a part of the model. In this case, the heat sink fins design with the base will be under its rule which is the air domain at the same time as shown in **Figure 7**. It is colored with purple.

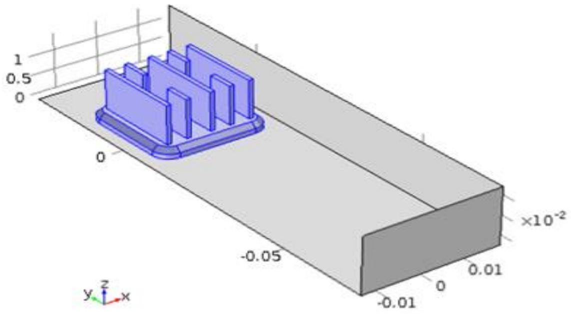

Figure 7. heat transfer in solids boundary condition.

The second boundary condition is Thermal Insulation. These boundaries prevent heat transfer through them to provide perfectly-insulated boundary. This boundary condition, shown in **Figure 8** with purple color, was used at the boundaries of the base of the heat sink and the inner surfaces of the rectangular prism containing the heat sink. This was done to prevent convective cooling from taking place on these surfaces to simulate the device in real-world situations. In addition, the meaning of thermal insulation that the temperature equals zero, therefore there is no heat flow.

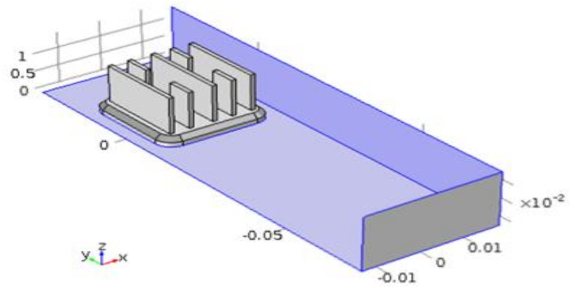

Figure 8. Thermal insulation boundary condition.

After the default boundary condition is set, now another boundary conditions must be set to completely define the physics of the heat sink model. One of the main boundary conditions to be added is the heat source boundary condition as shown in

Figure **9** that represents the electronic chip that generates heat. The form of the heat generated used is the convective heat flux in watts per square meter which equals to:

$$q_0 = h\,.(T_{source} - T) \tag{3}$$

Where q_0 is the convective heat flux in watts per square meter is, h is the Heat transfer coefficient between the heat sink and the heat source and equals 300 W/($m^2.K$), T_{source} is the heat source temperature and equals 100°C and T is the temperature of the model evaluated by the simulation.

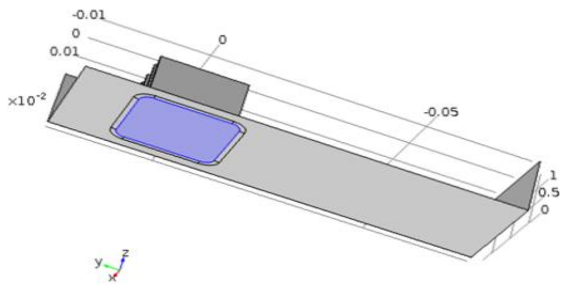

Figure 9. Heat source boundary condition.

The other boundary conditions to be added are the coolant flow directions and its conditions. The inlet direction of the coolant is shown in Figure 10, the velocity of the coolant at the inlet is 1 m/s, and the inlet temperature 22°C

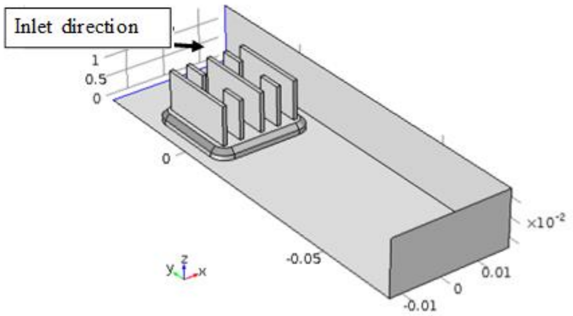

Figure 10 . Coolant inlet direction.

The out-flow direction of the coolant is shown in Figure 11, colored with purple. At the out-flow pressure equals zero.

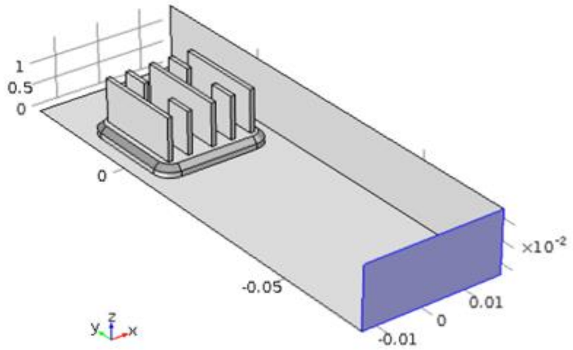

Figure 11. Outlet boundary condition.

3. Adaptive Neuro Fuzzy Inference System (ANFIS)

ANFIS (Adaptive Neuro Fuzzy Inference System) is defined as a single framework that combines both concepts of Artificial Neural Network and Fuzzy Logic. ANFIS combines the decision making of a fuzzy inference system and the learning abilities of neural network. The advantage of using the fuzzy inference system is to transact with the linguistic expressions, where the advantage of the neural network is its ability of learning. Jang, 1993 [19] benefits from these advantages, by combining the two techniques, and proposed the ANFIS approach. The hybrid combination, ANFIS, of both techniques allows self-learn and self-improve simulation environment. ANFIS approach uses a fuzzy system to represent the information in an illustratable manner, which has the learning ability obtained from the neural network that can tune the membership function parameters and linguistic rules, to enhance the system performance [20].

There are several fuzzy methods, such as fuzzy C-Means, fuzzy K-Means and subtractive clustering. Fuzzy clustering methods are implemented to identify the membership functions by arranging data samples into multiple distinguished clusters. The data samples, which share similar characteristics are arranged within one distinguished cluster.

The subtractive clustering method [21] considers all data points as potential cluster center, then calculates a measure of the possibility so that all of the data points would define the cluster center on the basis of the density of surrounding data points. The algorithm of subtractive clustering model follows the sequence of three main steps. First, the highest potential data point is selected to be the first cluster center. Then, the range of each data point influence (radius) is calculated based on the first cluster center, and to remove all data points from the first cluster vicinity. Finally, the second step iterates until each data point is placed within the radii of the related cluster. The subtractive cluster method is controlled by several parameters, which can be listed as follows:

The Range of influence: This parameter indicates the radius of the cluster, where the data space is taken to be a unit hypercube. The preferred values of cluster radii are usually selected between 0.2 and 0.5 [20]. A cluster with a small radius usually generates many small clusters, where having multiple small clusters causes a waste of computational resources. The cluster radii can vary over the entire domain, for example, for a multidimensional domain, the cluster radii can be chosen to have different values in each space domain dimension. In case of selecting a fixed radii value for the entire domain, then each cluster center will have a spherical neighborhood of influence with a radius equals the cluster radii. In this paper, the cluster range of influence is selected to be a fixed value for the entire domain and equals 0.5.

Squash factor: This factor magnifies the radii value to determine the neighborhood of each cluster. The neighborhood points represent the ones that will be considered to move into/from the specified cluster. The value of the squash factor is determined based on the distance between the cluster center and space domain, for example, a squash factor with value equals 20 is needed in case of the large distance between clusters centers. For the presented domain in this paper, the squash factor is set to be 1.25.

Accept ratio: The accept ratio determines the qualified points to join a cluster or not by calculating the potential fraction of each point with respect to the cluster center potential. The points which have a potential fraction value higher than the accept ratio limit are only qualified to join the designated cluster. The accept ratio varies from 0 to 1, and usually, the value of the accept ratio is selected to be high enough, so only points with strong potential are accepted to join the cluster. In the present work, the accept ratio is set to 0.5.

Reject ratio: The functionality of this parameter is opposed to the acceptance ratio parameter. Based on the fraction potential values between the data point potential and cluster center potential, the rejection criteria of that point are set to determine to send that point outside the cluster domain. In this work, the reject ratio is set to 0.15.

In this work, COMSOL is used to evaluate the pressure drop for the ladder heat sink design in its three cases of one link, two links and three links whether it is cooled by air or water. Since COMSOL needs a long time for simulation, it is only used to generate training data for ANFIS.

ANFIS system is built to predict the pressure drop value for any combination of dimensions. Six ANFIS systems were built to predict the pressure drop value for any combination of dimensions for the three designs of ladder heat sinks: one link, two links, and three links. Each model has been simulated by considering two different cooling fluids; water, and air.

An ANFIS toolbox is used to build the ANFIS schematic system. First, training data obtained from COMSOL with known characteristics have been loaded to the toolbox. Then, the subtractive clustering model is selected to build the ANFIS system. Finally, ANFIS performs a calibration process to tune the membership functions of fuzzy logic and construct the clusters. **Table 1** shows training data, which have been used to construct the ANFIS system for the one link-air cooled ladder heat sink design.

Table 1. Pressure drop values of one link air cooled ladder heat sink design

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure Drop (Pa)
0.0150 x 0.00050 x 0.0050	2.2824
0.0150 x 0.00050 x 0.0075	1.6571
0.0150 x 0.0050 x 0.01	1.3598
0.0175 x 0.00075 x 0.0050	2.5772
0.0175 x 0.00075 x 0.0075	1.9102
0.0175 x 0.00075 x 0.01	1.5668
0.0200 x 0.0010 x 0.0050	3.0075
0.0200 x 0.0010 x 0.0075	2.2327
0.0200 x 0.0010 x 0.01	1.8339
0.0150 x 0.00075 x 0.0050	2.4848
0.0150 x 0.00075 x 0.0075	1.8152
0.0150 x 0.00075 x 0.01	1.4940
0.0175 x 0.0005 x 0.0050	2.3833
0.0175 x 0.0005 x 0.0075	1.7201
0.0175 x 0.0005 x 0.01	1.4254
0.0200 x 0.00075 x 0.0050	2.6692
0.0200 x 0.00075 x 0.0075	1.9782
0.0200 x 0.00075 x 0.01	1.6482

4. Results and Discussions

In this section, results obtained for the different heat sinks simulated designs will be discussed. The designs under consideration include the parallel plate, elliptical, and ladder (one link, two links, and three links) designs. In each simulation, separately, air and water have been used as cooling fluid. COMSOL Multiphysics software has been used to simulate these models, along with, the predicted pressure drop values, for ladder sink models, from ANFIS systems.

4.1. Results of the Simulation in COMSOL

The performance of heat sink designs is evaluated based on the temperature of a point at the top surface of the heat sink fins, the velocity of the cooling fluid, pressure drop and the cooling power to dissipate heat.

Temperature Profile:

Figure 12, Figure 13, Error! Reference source not found., Figure 15, and Figure 16 show the temperature profile for heat sink designs, they show the temperature distribution on the fins. Also, shows the Temperature of the top surface of the fins of the heat sink designs.

Table 2. Temperature of the top surface of the fins for the heat sink designs

Model	Temperature of the top surface of the fins (°C)
Elliptical	62.2
Parallel plate	60.8
Ladder-one link	60.0
Ladder-two links	60.3
Ladder-three links	60.3

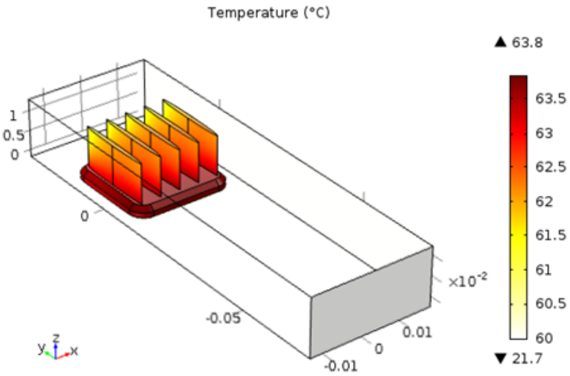

Figure 12 . Temperature profile of the elliptical heat sink design.

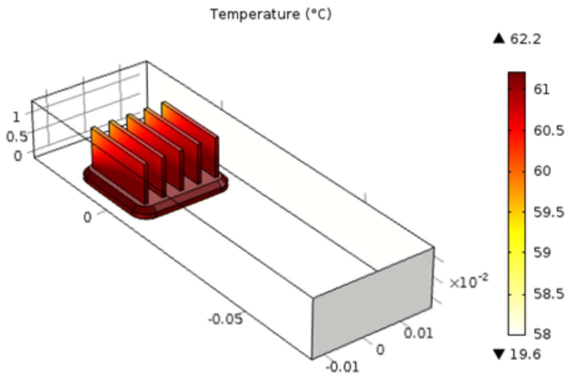

Figure 13 . Temperature profile of the parallel plate heat sink design

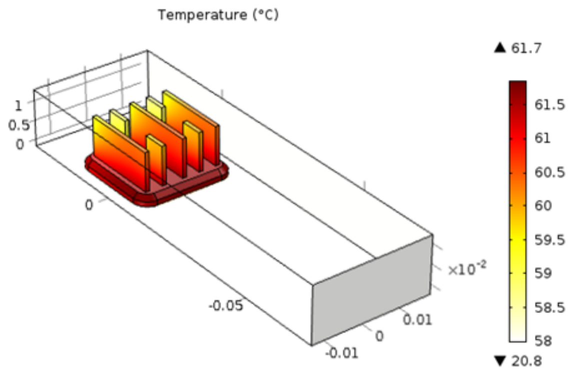

Figure 14 . Temperature profile of the one link ladder heat sink design

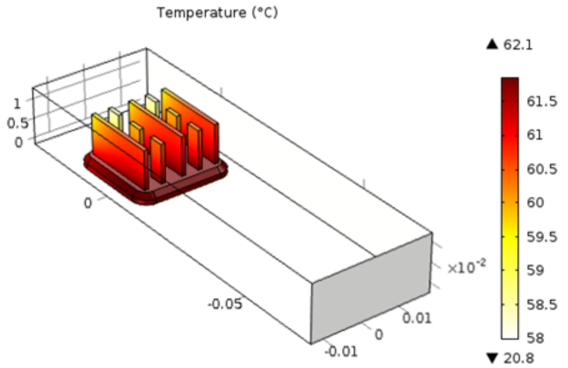

Figure 15 . Temperature profile of the two links ladder heat sink design

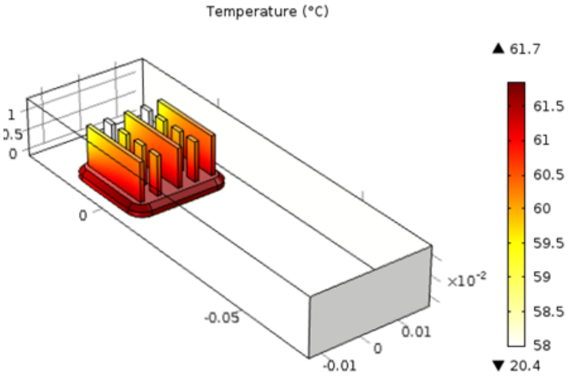

Figure 16 : Temperature profile of the three links ladder heat sink design

Results show that ladder heat sink design has the lowest value against the elliptical and rectangular heat sink design. This means that the ladder heat sink design has better performance than the other designs in terms of temperature.

Velocity Profile:

The second parameter in evaluating the heat sink performance is the velocity of the coolant while it is passing through the fins. As the velocity of the coolant increases, the coolant will cool the fins efficiently. So, it is evident that the increase in velocity will improve the heat sink performance. **Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, and **Figure 21** show the velocity profile of the heat sink designs. For the one-link ladder heat sink design, the maximum velocity is found to be around 2.2 m/s inside the electric chip domain. Also, **Table 3** shows the values of the maximum fluid velocity of the coolant passing the heat sink designs.

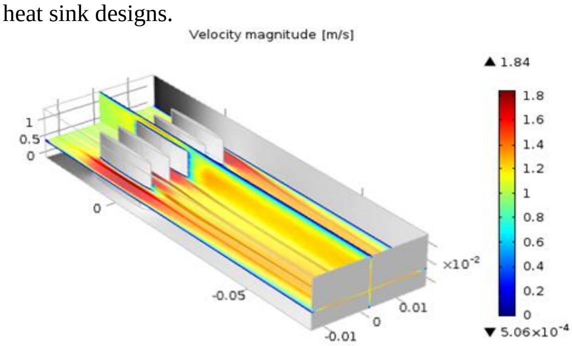

Figure 17. Velocity profile of the elliptical heat sink design

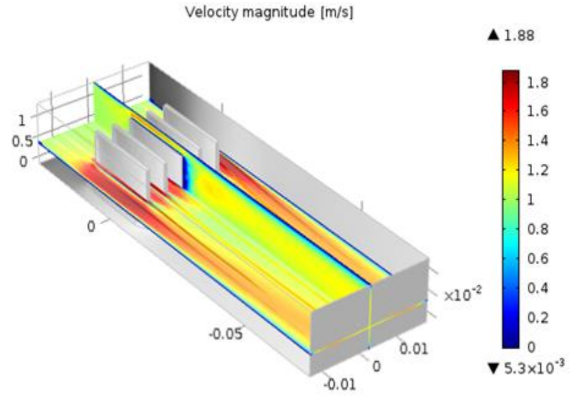

Figure 18. Velocity profile of the parallel plate heat sink design

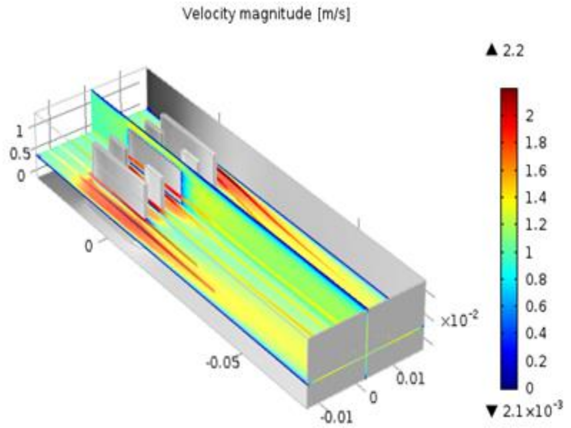

Figure 19. Velocity profile of the one link ladder heat sink design

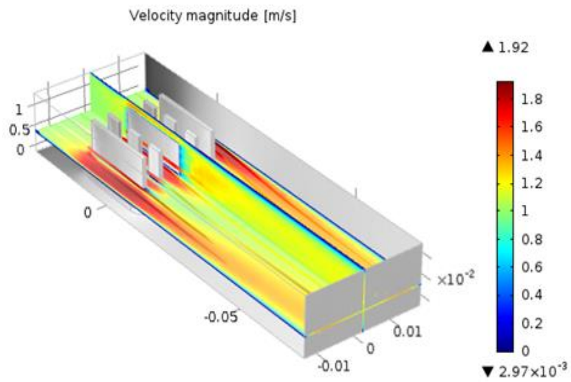

Figure 20. Velocity profile of the two links ladder heat sink design

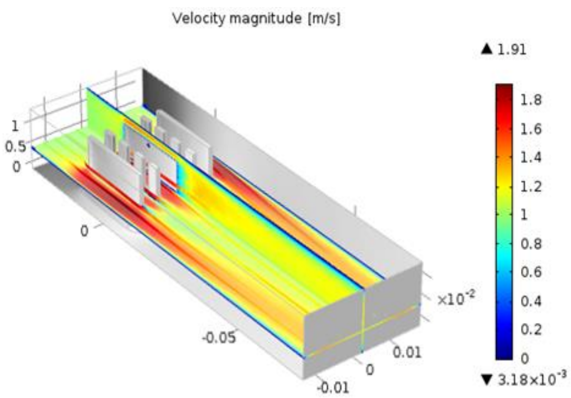

Figure 21. Velocity profile of the three links ladder heat sink design

Table 3. Maximum fluid velocity of the coolant passing the heat sink designs

Heat sink design	Fluid velocity (m/s)
Elliptical	1.84
Parallel plate	1.88
Ladder-one link	2.02
Ladder-two links	1.92
Ladder-three links	1.91

It can be clearly inferred from the velocity profiles of the heat sink designs, that the ladder design with one link has the maximum velocity compared with the other designs. Also, two links ladder design and three links ladder design have better results than the elliptic and parallel plate design. One link ladder heat sink design is 20% and 17% more efficient than elliptical and parallel plate heat sink design respectively. This high velocity causes higher turbulence and mixing between the heat sink and the cooling fluid, and that enhance heat removal.

Cooling Power Calculations:

COMSOL can integrate and perform several computational operations on the obtained results. The cooling power of a heat sink can be calculated by computing the surface integration of the heat source. The cooling power of a heat sink, Q (W/m^2) is given by Eqn. 4:

$$Q = h_c(T_{ext} - T) \tag{4}$$

Where h_c $(W/m^2.°C)$ is the convection heat transfer coefficient between the heat sink and the heat source and equals to $300(W/m^2.°C)$. $T_{ext.}$ $(°C)$ denotes the temperature of the heat source and equals to $100°C$ .T $(°C)$ represents the temperature distribution.;

The cooling power values of each simulated case are shown in Table 4. The higher cooling power value reflects a better efficiency in terms of heat removal. The ladder heat sinks have a higher cooling power compare to both parallel and elliptic designs.

Table 4. Cooling power of different heat sink design, using air as cooling fluid

Model	Cooling Power (W/m^2)
Elliptic	5.47
Parallel Plate	5. 70
Ladder – one link	5.77
Ladder – two links	5.77
Ladder – three links	5.77

Pressure Drop:

The increase in pressure drop causes a rise in the mean velocity, which increases the volumetric flow and that enhance the heat removal. Also, at higher pressure drop the flow fluctuation of the cooling fluid becomes a dominant, which in improving heat transfer removal from the fins. The average pressure drop has been obtained from COMSOL software. The results show that the ladder heat sinks have higher pressure drop compare to elliptic and parallel plate heat sinks. The average pressure drops in the ladder heat sink of one, two and three links are 1.84, 1.80 and 1.83Pa respectively. Where the average pressure drop in elliptic and parallel plate sinks are 1.49 and 1.71Pa, respectively.

Clearly, the ladder heat sink design has the best performance over the other heat sink designs, in terms of heat dissipation. Also, the cost of ladder heat sinks is expected to be lower than the parallel plate design, due to the reduction of used material by causing gaps between the fins in the ladder sinks.

4.2. Results of ANFIS

ANFIS system has been used to predict the pressure drop. ANFIS system with subtractive clustering method is used. After ANFIS system is being calibrated using the training data in **Table 1.** the ANFIS system can predict the pressure drop for any geometry based on its dimensions as shown in Error! Reference source not found..

To compare COMSOL to ANFIS results, the root mean square (RMS), is used to measure the percentage error between the obtained results. RMS can be defined as follows:

$$Percentage\_error = \left| \frac{P_{comsol} - P_{ANFIS}}{P_{comsol}} \right| \% \qquad (5)$$

Where p_{comsol} and p_{ANFIS} are the pressure drop value from COSMOL and ANFIS respectively.

Table 5 . ANFIS results for ladder with one link air cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure Drop from COMSOL (Pa)	Pressure Drop from ANFIS (Pa)	Percentage Error (%)
0.0170 x 0.00065 x 0.53	2.38	2.57	7.98%
0.0190 x 0.00090 x 0.90	1.85	1.89	2.16%
0.0165 x 0.00060 x 0.60	2.08	2.27	9.13%
0.0155 x 0.00100 x 0.65	2.28	2.1	7.89%
0.0200 x 0.00075 x 0.77	1.94	2.07	6.70%
0.0180 x 0.00080 x 1.00	1. 61	1.57	2.48%
0.0175 x 0.00050 x 0.75	1.72	1.78	3.49%
0.0185 x 0.00085 x 0.85	1.83	1.87	2.19%
0.0150 x 0.00055 x 0.80	1.61	1.65	2.48%
Average percentage error			4.95%

Table 6. ANFIS results for ladder with two links air cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure Drop from COMSOL (Pa)	Pressure Drop from ANFIS (Pa)	Percentage error (%)
0.0170 x 0.00065 x 0.53	2.36	2.45	3.81%
0.0190 x 0.00090 x 0.90	1.83	1.85	1.09%
0.0165 x 0.00060 x 0.60	2.08	2.18	4.81%
0.0155 x 0.00100 x 0.65	2.87	2.09	27.18%
0.0200 x 0.00075 x 0.77	1.94	1.93	0.52%
0.0180 x 0.00080 x 1.00	1.61	1.59	1.24%
0.0175 x 0.00050 x 0.75	1.74	1.73	0.57%
0.0185 x 0.00085 x 0.85	1.61	1.75	8.70%
0.0150 x 0.00055 x 0.80	1.62	1.55	4.32%
Average percentage error:			5.80%

Table 7. ANFIS results for ladder with three links air cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure drop from COMSOL (Pa)	Pressure drop from ANFIS (Pa)	Percentage error (%)
0.0170 x 0.00065 x 0.53	2.42	2.57	6.20%
0.0190 x 0.00090 x 0.90	1.81	1.89	4.42%
0.0165 x 0.00060 x 0.60	2.08	2.27	9.13%
0.0155 x 0.00100 x 0.65	2.29	2.09	8.73%
0.0200 x 0.00075 x 0.77	1.94	1.78	8.24%
0.0180 x 0.00080 x 1.00	1.60	1.57	1.88%
0.0175 x 0.00050 x 0.75	1.73	1.78	2.89%
0.0185 x 0.00085 x 0.85	1.84	1.86	1.09%
0.0150 x 0.00055 x 0.80	1.61	1.66	3.10%
Average percentage error:			5.08%

Table 8: ANFIS results for ladder with one link water cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure drop from COMSOL (Pa)	Pressure drop from ANFIS (Pa)	Percentage error (%)
0.0170 x 0.00065 x 0.53	882.50	935	5.95%
0.0190 x 0.00090 x 0.90	806.20	810	0.47%
0.0165 x 0.00060 x 0.60	787.50	831	5.52%
0.0155 x 0.00100 x 0.65	972.74	795	18.27%
0.0200 x 0.00075 x 0.77	792.78	811	2.30%
0.0180 x 0.00080 x 1.00	706.50	688	2.62%
0.0175 x 0.00050 x 0.75	665.68	666	0.05%
0.0185 x 0.00085 x 0.85	775.28	787	1.51%
0.0150 x 0.00055 x 0.80	631.21	650	2.98%
Average percentage error:			4.41%

Table 9. ANFIS results for ladder with two links water cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure drop from COMSOL (Pa)	Pressure drop from ANFIS (Pa)	Percentage error (%)
0.0170 x 0.00065 x 0.53	875.54	925	5.65%
0.0190 x 0.00090 x 0.90	783.87	812	3.59%
0.0165 x 0.00060 x 0.60	785.49	824	4.90%
0.0155 x 0.00100 x 0.65	971.57	785	19.20%
0.0200 x 0.00075 x 0.77	794.38	819	3.01%
0.0180 x 0.00080 x 1.00	704.17	688	2.30%
0.0175 x 0.00050 x 0.75	674.57	669	0.83%
0.0185 x 0.00085 x 0.85	769.19	791	2.84%
0.0150 x 0.00055 x 0.80	627.67	645	2.76%
Average percentage error:			5.02%

Table 10. ANFIS results for ladder with three links water cooled

Channel Dimension Length (m) x Width (m) x Height (m)	Pressure drop from COMSOL (Pa)	Pressure drop from ANFIS (Pa)	Percentage error (%)
0.0170 x 0.00065 x 0.53	856.41	923	7.78%
0.0190 x 0.00090 x 0.90	779.02	809	3.85%
0.0165 x 0.00060 x 0.60	781.83	825	5.52%
0.0155 x 0.00100 x 0.65	780.83	783	0.28%
0.0200 x 0.00075 x 0.77	987.74	728	26.29%
0.0180 x 0.00080 x 1.00	694.68	681	1.97%
0.0175 x 0.00050 x 0.75	669.51	675	0.82%
0.0185 x 0.00085 x 0.85	773.44	781	0.98%
0.0150 x 0.00055 x 0.80	640.71	643	0.36%
Average percentage error:			5.32%

The evaluated percentage error values show that the average errors between COMSOL and ANFIS results for one, two and three links are 4.95%, 5.80% and 5.08%, respectively, in case of using air as the working fluid. In the case of using water, the RMS values for one, two and three links are 4.41%, 5.02% and 5.32%, respectively.

5. Conclusion

In this work, the thermal performance of different heat sinks has been investigated. A new heat sink design, ladder model, has been presented. The proposed model is formed by making a gap in a fin which lays between two parallel rectangular fines. Several comparison studies have been conducted between the elliptical heat sink design and parallel plate heat sink design, with the ladder heat sink design.

Results show that proposed heat sink design; the ladder heat sink design has best performance among the other heat sink designs. The maximum temperature of the top surface reached in the ladder heat sink design is 60.8°C while in the other heat sink designs the temperature was higher. The velocity of the coolant was in ladder heat sink design was 2.2m/s but the other heat sink designs shows lower values. In addition, pressure drop value of the ladder heat sink design is the highest one with value of 1.84 Pa. Finally, the cooling power of the heat sink design is evaluated for each heat sink design, it was found that the ladder heat sink design has the highest cooling power.

Results show that the ladder heat sink design has the best performance in comparison with two heat sinks designs, namely, elliptical and parallel plate heat sink design according to the following parameters: the temperature of the top surface of the fins after the cooling, the velocity of the coolant, pressure drop value and the cooling power of each heat sink design.

ANFIS is used to predict the pressure drop value. Six identical ANFIS models were built to predict the pressure drop value for the three cases of ladder heat sink designs (one link, two links and three links) and the two coolants: air and water. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for one link and air-cooled ladder heat sink design is 4.95%. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for two links and air-cooled ladder heat sink design is 5.80%. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for three links and air-cooled ladder heat sink design is 5.08%. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for one link and water-cooled ladder heat sink design is 4.41%. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for two links and water-cooled ladder heat sink design is 5.02%. The average percentage error between the predicted value from the ANFIS model and the real value obtained from COMSOL for three links and water-cooled ladder heat sink design is 5.32%. Results show that ANFIS is a powerful tool for modeling according to percentage error.

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