J Ther Eng, Vol. 10, No. 1, pp. 10–20, January, 2024

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1428967

Research Article

Investigation into the heat sink performance of the inline and cut cross fins types using different aluminum alloys

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ARTICLE INFO

Article history
Received: 27 June 2022
Accepted: 17 February 2023

Keywords:
Inline; Cut Cross; Passive Heat Sink; Aluminum Alloys

ABSTRACT

In this study, two types of heat sinks are selected at similar dimensions. In addition, five types of aluminum alloys are used to find the optimum performance for both models' inline and cut cross heat sinks. These types of alloy materials were Al-1100, Al-3063, Al+25%Ni, and Al+25%Cu that are selected and compared with pure aluminum. The effectiveness results showed of the heat sink using Al- 25%Cu has the highest value compared to the other material types Al- 25%Ni, Al 1100, and Al 6063 respectively. While the lowest value of the fin efficiency was observed for pure aluminum. Moreover, the heat sink using Al- 25%Ni, Al 1100, and Al 6063 has moderate values. The results also indicated that the rate of heat-dissipated from the cut cross heat sink increases, as the fin thickness increases until reaches maximum value before it decreases with an increase in the fin thickness. While for the inline heat sink, the heat transfer increases as the fin thickness increase before stables at 2 mm approximately.

Cite this article as: Nazzal IT, Salem TK, Farhan SS, Tahseen TA. Investigation into the heat sink performance of the inline and cut cross fins types using different aluminum alloys. J Ther Eng 2024;10(1):10–20.

INTRODUCTION

Nowadays, the large development in electronic devices is accompanied by an increase in heat dissipation from electronic devices. As a result, electronic cooling becomes essential to keep these devices' operating temperatures within their desired limits [1, 2]. One of the effective methods of cooling electronic devices is a heat sink which is that used to dissipate the heat from a hot surface. Many studies have dealt with many types of heat sinks and their performance [3, 4]. These studies showed that many parameters influence the performance of the heat sink, for instance, the shape of the sink, material type, fin shape, etc. Consequently, researchers have used many ways to improve the heat sinks based on these parameters [5, 6]. An overview of various types of heat sinks related to design parameters was introduced by Lee [7]. Culham and Muzychka [8] demonstrated an investigation for the optimization of heat sink design parameters for the plate-fin-type heat sink. This study indicated that aluminum is a typical material for heat sinks because of offering a good balance between cost, weight,

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This paper was recommended for publication in revised form by Regional Editor Erman Aslan

Published by Yıldız Technical University Press, İstanbul, Turkey

and thermal properties [9]. Two-layer small-channel heat sinks with opposite arrangements of flow were studied in terms of thermal performance by vafai and Zhu [10]. Chein and Huang [11] conducted a study to analyze the performance of a heat sink for two microchannels with a specific geometry and using nanofluids (Cu - H_2O). The results of their study showed that the use of nanofluids leads to an improvement in the performance of the heat sink for the two micro-channel geometries. Yang et al. [12] provided a comparative investigation of the performance of pin fin heat sinks with different shape pins (circular, elliptic, and square cross-sections). They showed that for the same surface area, the elliptic pin fin possesses achieved the highest thermal performance and the lowest pressure drops for the staggered arrangement. The thermal performance using different fin configurations of the heat sink for power electronics is introduced by Han and Jeong [13]. They noticed that the heat sink using the perforated fins offers excellent thermal performance compared with that flat plat due to the increase in the increment rate of the dissipation heat area. Al-Sallami et al. [14] studied numerically the simple longitudinal notch and slot perforations in perforated fin heat sinks and compared their performance with circular longitudinal perforations. They concluded that both slot and notch perforations offer significant improvement over circular perforations in terms of pressure drop and heat transfer. An experimental study was conducted by Jaffal [15] to study the effect of the fin shape on the performance of a heat sink, with sing six different forms of fins which were (flat plate, cross-cut, perforated, perforated - cut, serpentine, zigzag). The results obtained showed that the best thermal performance was for the heat sink with fins in the form of (perforated - cut). Sakanova and Tseng [16] presented a study for a comparison of finned shape and pin-fin heat sinks for power electronics. They found that the Pin-fin shape present overcomes the finned shape in terms of the thermal performance of the heat sink. Khurshid et al. [17] introduced an analytical study to design a heat sink for an electric drive based on natural convection by using two types of fins (rectangular plate and rectangular pin). They found that the heat transfer coefficient affects both the rate of heat transfer and the shape of the fin. Optimization for radial plate-fin heat sinks was presented by [18]. They introduced design guidelines for radial plate-fin heat sinks. Tariq et al. [19] demonstrated a comparison of the thermal performance of improving plate-fin heat sinks. They used plate-fin heat sinks with slots and perforations. Their investigation indicated that plate-fin heat sinks with slots and perforations give a significant advantage over plane plate fins in terms of pressure drop and heat transfer. The thermal performance study of a plate-fin perforated twisted and twisted tape were introduced by Nılpueng and Wongwıses [20]. They concluded with adding semicircular to straight fins array of heat sink give a high heat transfer compared to all other types of heat sink arrays.

Depending to previous studies, aluminum is the main material used to manufacture heat sinks [21]. Nevertheless, the effect of the aluminum alloys on the thermal performance of the heat sink was tested by many researchers such as Rehman and Ali [22]. They examined the effect of Nickel foam and Copper on its performance. They concluded that coper offers better results than the others. Modified polymeric instead of aluminum was also used in manufacturing the heat sink by Rohani et al. [23]. They noticed that enhancement in the thermal conductivity and heat transfer with using these types of materials. Finally, a theoretical study of the heat sink performance with pin fins was conducted by Nazzal et al. [24]. They used various types of alloys (beryllium - aluminum, copper - aluminum) fins. The results showed that the performance of the heat sink had the highest value with using copper - aluminum) alloy and lowest value with using (beryllium - aluminum) alloy compared to pure aluminum.

The finding of the previous studies indicated that many parameters that influence the performance of the heat sink. These parameters involve the material of the sink, shape of the sink, fin shape, etc. Moreover, these studies introduced an inline cut cross of the heat sink shape. Despite continuous studies on the heat sink and its performance, a comparative investigation for cut and inline heat sinks with various types of materials has not been studied. Thereby, two inline and cut cross was selected to achieve this study. Moreover, five types of materials and alloys have been used. Consequently, a comparative study of the heat sink performance of the inline and cut cross heat sink with different alloys materials will be introduced.

ANALYTICAL AND NUMERICAL MODELS

A passive cooling system contains three parts chip, interface material, and heat sink. The passive system dimensions for two types of heat sinks are illustrated in Figures (1A and B). A chip dimension 20 mm×20 mm×10 mm was placed at the center of the lower surface of the heat sink base assuming the amount of heat dissipated from the chip was around 100 Watts and thermal conductivity 140 W/m·K.

Next, a thermal interface material had been utilized to reduce the contact thermal resistance between the chip and heat sink base with its thermal conductivity and thickness being 2 W/m·K and 0.1mm respectively. Finally, the boundary dimensions of the heat sink are 100mm×100mm×110mm. In addition, the thermos-physical properties, cost, and chemical composition of the Aluminum alloys have been shown in Table 1 (A and B).

To optimize the heat sink performance for two types the cross-cut pin fins and inline are determined by considering different parameters. For more explanation, the parameters are types of Aluminum materials, and the properties of the heat sink as density, thermal conductivity, specific heat, and mass. In addition, the thermal properties of the heat sink are calculated such as overall efficiency, coefficient of the heat

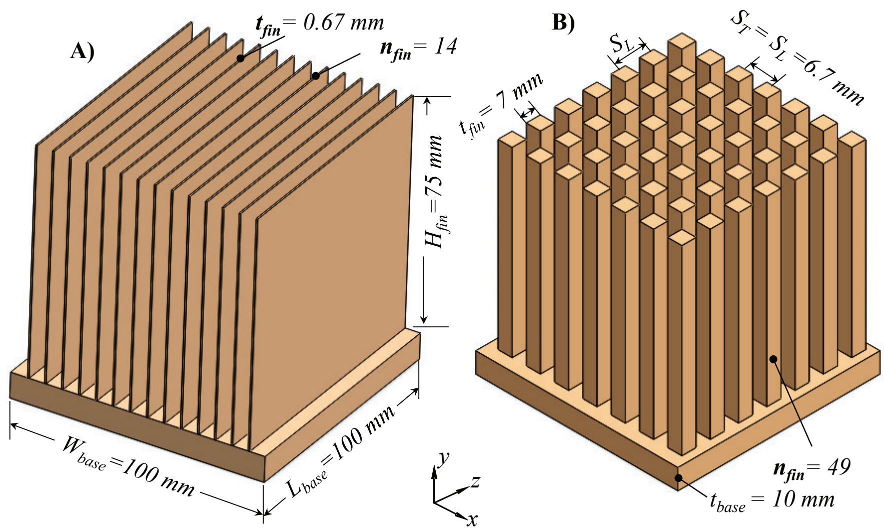

Figure 1. Schematic diagrams of different heat sinks; A) inline and B) Cross-cut pin fins.

Table 1. Aluminum alloy properties, cost A) and Chemical Composition B)

A) Alloy	Density kg/m³	K W/m.k	C J/kg.k	Cost per lb for US $	Cost per kg for US $
AL-pure	2700	237	869	0.92	2.0283
AL+25% Ni	4520	192.18	790	2.4875	5.484
AL+25%Cu	4262	273.25	768	1.4525	3.2022
Al 1100	2710	218	900	0.82	1.8078
Al6063	2700	209	900	0.71	1.5653

B) Chemical Composition Limits

Weight%	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other Each	Others Total
6063	Balance	0.2 - 0.6	0.35	0.1	0.1	0.45- 0.9	0.1	0.1	0.1	0.05	0.15
1100	Rem	0.45	0.5	0.05-0.02	0.05	-	-	0.10	-	0.05	0.15

transfer, thermal resistance, and finally the Nusselt number [21]. The thermal resistances for each part of the heat sink are the major parameter to calculate its performance [22] and [23] (see Figure 2). Then, the overall thermal resistance of the heat sink had been calculated by summing all thermal resistances for each component of it such as the chip, interface, heat sink base, fins, and un-fins (see Figure 1).

The contact thermal resistance is a very important point for reducing the temperature drop which means low interface resistance leads to considering it a good conductor of heat. Many parameters affect the thermal interface resistance as the interface thickness, surface roughness, interface thermal conductivity, and the number of interface layers. Therefore, the thermal interface resistance can be calculated by:-

$$R_{interface} = \frac{t_{interface}}{A_{interface} * K_{interface}} \tag{1}$$

However, the thermal resistance of the heat sink base is determined as a function of the thermal conductivity, thickness, and cross-section area of the heat sink base as follows:-

$$R_{base} = \frac{t_{base}}{A_{base} * K_{base}} \tag{2}$$

Then, the thermal resistance of the chip can be calculated by:

$$R_{chip} = \frac{t_{chip}}{A_{chip} * K_{chip}} \tag{3}$$

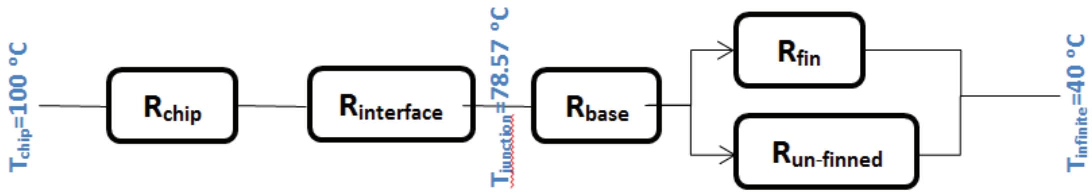

Figure 2. Resistance network representing the Chip, interface &heat sink.

In this study, the major resistance within the total thermal resistance is the fin thermal resistance of the heat sink that is calculated by considering different parameters such as the fin efficiency, fin surface area, and the heat transfer coefficient. Two mechanisms of heat transfer are considered for analyzing the thermal contact resistance of the fin such as thermal conduction and convection. In general, heat can be transferred from the fins by conduction through the fin and also by convection from the fin to the ambient air. Consequently, the fin thermal resistance can be calculated by:-

$$R_{fin} = \frac{1}{h_{fin} * \eta_{fin} * A_{fin}} \tag{4}$$

For unfinned surface areas, the thermal resistance of exposed area without fins is given by [21]:-

$$R_{unfinned} = \frac{1}{(h_{unfinned} * A_{unfinned})} \tag{5}$$

Therefore, the total thermal resistance of the heat sink can be calculated as a function of the fin and unfinned thermal resistance as follows: -

$$R_{HS} = \frac{1}{\frac{1}{R_{fin}} + \frac{1}{R_{unfin}}} \tag{6}$$

Then, the total thermal resistance is:-

$$R_{total} = R_{interface} + R_{base} + R_{HS} + R_{chip} \tag{7}$$

Thus, the overall heat transfer rate is defined, as the ratio of the temperature difference to the total thermal resistance as follows: [24]:-

$$Q_{total} = hA_{total}(T_b - T_a) = \frac{T_J - T_a}{R_{total}} \tag{8}$$

In this study, the amount of heat transfer rate from the fins is indicated by following this equation [25]:

$$Q_{fin} = (hpkAc)^{1/2}(T_b - T_a)tanh(mL) = \eta_{fin} * Q_{fin,max} \tag{9}$$

Where

$$Q_{fin,max} = A_{fin}h(T_b - T_a)$$

In another expression, the total heat dissipated from the system can be determined by summing the rate of heat transfer from the fins surface and unfinned surface [26]:

$$Q_{total} = Q_{unfin} + Q_{fin} \tag{10}$$

And the dissipation of heat from the unfinned surface to the ambient can be calculated by [27]

$$Q_{unfin} = A_{unfin}h(T_b - T_a) \tag{11}$$

The fin effectiveness and overall fin effectiveness for each type of heat sink can be calculated by these relations[21]:

$$\varepsilon_{fin} = \frac{Q_{fin}}{hA_b(T_b - T_a)} \tag{12}$$

And

$$\varepsilon_{fin,overall} = \frac{Q_{total}}{Q_{unfin}} = \frac{Q_{unfin} + Q_{fin}}{hA_b(T_b - T_a)} \tag{13}$$

The optimum spacing between the fins for the two types of heat sink is calculated by[27]:-

$$\mathrm{Z_{opt}} = 3.24 * \mathrm{L_{base}} * Re^{-0.5} * Pr^{-0.25} \tag{14}$$

For the cut cross pin fins, the optimum spacing as longitudinal pitches SL and transverse pitches ST are determined by using the above equation (14) that gave the same value of Zopt and means SL=ST=Zopt.

The development of the heat transfer coefficient for the unfinned and finned surfaces is achieved by Khan et al. [22] as written: -

$$h_{unfinned} = \frac{0.75K_f}{D_{h\_fin}}\sqrt{\frac{S_T - 1}{\eta_{fin,L}S_LS_T}}Re_{D_h}^{0.5} * Pr_{D_h}^{0.3} \tag{15}$$

$$h_{fin} = \frac{C_1K_f}{D_{h\_fin}}Re_{D_h}^{0.5} * Pr_{D_h}^{0.3} \tag{16}$$

Where the coefficient C1 in the above equation is calculated by[27]:-

$$C_1 = [0.2 + e^{(-0.55S_L)}]S_T^{\ 0.285}\ S_L^{\ 0.212} \tag{17}$$

The average coefficient of heat transfer of the heat sink type cut cross-pin fins can be determined by combining the equations (14, 15, and 17):

$$h_{unfinned} = C_2 \frac{K_a}{D_{h\_fin}} Re_{D_h}^{0.5} * Pr_{D_h}^{1/3} \tag{18}$$

Where the coefficient C2 is a constant for cut cross pin fin and can be found as[25]:

$$C_2 = \frac{C_1 \pi \gamma \eta_{fin} + 0.75 \sqrt{\frac{S_T - 1}{n_{fin,L} S_L S_T}} (S_T S_L - \frac{1}{4})}{\pi(\gamma - \frac{1}{4}) + S_T S_L} \tag{19}$$

For the pin fins: the aspect ratio is calculated by: $\gamma = \frac{H}{D_h}$

For the inline heat sink, the coefficient of heat transfer is given by [21]:-

$$h_{fin} = 0.664 * \frac{K_{air}}{L_{base}} Re_L^{0.5} * Pr_L^{\frac{1}{3}} \tag{20}$$

The maximum velocity of working fluid (air) between the fins for each type of heat sink is used for completing the analytical calculations of the heat sink. For example, the output results are achieved from the analytical code such as fin efficiency, fin effectiveness, and the overall heat transfer rate. [28]:

$$U_{max} = max\left\{\frac{S_T}{S_T - 1} U_{ai}, \frac{S_T}{S_L - 1} U_{ai}\right\} \tag{21}$$

Thence, the other dimensionless parameter as a function of heat transfer coefficient is the Nusselt number that can be expressed as:

$$Nu_{inline\_HS} = \frac{h_a * L_b}{k_a} \tag{22}$$

$$Nu_{Cross\ pin\_HS} = \frac{h_{fin} * D_{h\_fin}}{k_a} \tag{23}$$

The fin efficiency and overall fin efficiency for the inline fins and cut cross-pin fins are calculated by using equations 24 and 25 respectively [21]:-

$$\eta_{\text{fin}} = \frac{\tanh\ (mH)}{\text{mH}} \tag{24}$$

$$\eta_{\text{overall}} = 1 - n_{fin} \frac{A_{fin}}{A_{total}} (1 - \eta_{\text{fin}}) \tag{25}$$

Where $m = \sqrt{\frac{4h_{fin}}{KD_{h\_fin}}}$ for the cut cross-pin fin

And $m = \sqrt{\frac{2h_{fin}}{Kt_{fin}}}$ for the inline fin

The analytical and numerical calculations had been achieved by utilizing EES code and Icepack ANSYS to discover the optimum design of the heat sink using different material alloys compared to the reference pure aluminum.

RESULTS AND DISCUSSION

The dependency of the heat sink performance on its configuration and material type has been investigated by using two shapes a cut cross and an inline pin fin. Moreover, five types of metallic alloys are selected to find the optimum performance using these types of the materials and configuration of the heat sink (See Table 2). The hot spots of the heat source are mounted on the center of the heat sink. The main parameters of heat sink performance are plotted as a function of thickness fin for both heat sink types and materials alloys types.

Figure 3 demonstrates a comparison of fin effectiveness for Al- 25%Cu, Al- 25%Ni, Al 1100, and Al 6063 for both inline and cut cross-sections versus different fin thicknesses of the heat sink. It can be noticed that from this Figure the effectiveness (ε), decreases as the fin thickness increases for the inline heat sink. While the effectiveness of the cut cross heat sink decreases before reaching a minimum value of 2.5 mm and stables. For the effect of the heat sink configuration, it can be noticed that from the Figure, the effectiveness of the inline heat sink is greater than that of the cut cross heat sink for all kinds of materials as can be observed in this Figure. This is because more heat can be transferred to the environment as the surface exchange area increases for the inline heat sink respected to that of the cut cross heat sink. In addition, the results show that the effectiveness of the heat sink using Al- 25%Cu has the highest value, which is higher than that of the Al- 25%Ni, Al 1100, and Al 6063 of the heat sink respectively. While the lowest value of the fin effectiveness was observed for pure aluminium. Moreover, the heat sink using Al- 25%Ni, Al 1100, and Al 6063 has moderate values. This trend can be explained to the fact; the thermal conductivity of the Al- 25%Cu is higher than that of the Al- 25%Ni, Al 1100, and Al 6063, which leads to an increase in the heat dissipated, i.e., an increase in the fin effectiveness. It can also be observed that the effectiveness of the inline heat sinks using Al-25%Cu, Al- 25%Ni,

Table 2. Al-pure inline and cut cross-pin fin heat sink dimensions in the Icepack program

Heat sink	tf (mm)	H=b (mm)	W (mm)	L (mm)	base (mm)	Z=s (mm)	nf	U_air (m/s)	Aunfin m^2	Qair (m^3/s)
Inline	0.668	90	100	100	10	6.667	14	1.5	0.009089	0.01363
Cut cross	7.11	90	100	100	10	6.667	51=49	1.5	0.007263	0.01089

Table 3. Sample of results for types heat sink inline and cut cross pin fin

THS	alloy	t_{fin_opt}	Cost	η_f	η_{0f}	ϵ_{fin}	$Mass_{al}$	η_{fin}	q_{total}	R_{total}
		[mm]	[$]	[%]	[%]	[-]	[kg]	[-]	[w]	[k/w]
inline	Al-1100	0.758	0.4501	69.79	70.86	1.664	0.249	13.47	100	0.3857
	optimum	1.578	0.8438	82.16	**82.79**	0.945	0.4668	12.13	106	0.3637
	Al-6063	0.81	0.4121	70.26	71.31	1.568	0.2633	13.37	100	0.3857
	optimum	1.578	0.7279	81.56	**82.21**	0.938	0.465	12.13	105.3	0.3663
	AL+25%Cu	0.548	0.933	67.86	69.0	2.235	0.2913	13.86	100	0.3857
	optimum	1.367	2.09	83.29	**83.88**	1.104	0.6526	12.45	110	0.3505
	AL+25%Ni	0.938	2.752	71.46	72.47	1.378	0.5018	13.15	100	0.3856
	optimum	1.578	4.269	80.32	**81.02**	0.924	0.7785	12.13	103.8	0.3717
	AL-pure	0.668	0.4492	68.96	70.06	1.864	0.2215	13.63	100	0.3857
	optimum	1.578	0.9439	83.3	**83.89**	0.958	0.4654	12.13	107.5	0.3589
Cut –cross pin fin	Al-1100	7.2	1.195	87.93	88.55	0.437	0.661	51.71	100	0.3857
	optimum	3.0	0.4247	58.41	**61.43**	0.701	0.2349	107.0	146.9	0.2626
	Al-6063	7.315	1.025	87.37	88.02	0.437	0.6551	52.01	100	0.3857
	optimum	3.0	0.3663	57.52	**60.6**	0.690	0.234	107.0	144.9	0.2662
	AL+25%Cu	6.82	3.412	90.53	91.01	0.439	1.066	50.32	100	0.3857
	optimum	3.0	1.183	63.17	**65.85**	0.758	0.3694	107.0	157.4	0.245
	AL+25%Ni	7.43	5.942	86.16	86.87	0.436	1.083	52.69	100	0.3857
	optimum	3.0	2.149	55.73	**58.94**	0.669	0.3918	107.0	140.9	0.2737
	AL-pure	7.11	1.35	88.97	89.53	0.438	0.6656	51.15	100	0.3856
	optimum	3.0	0.475	60.19	**63.07**	0.722	0.2342	107.0	150.8	0.2558

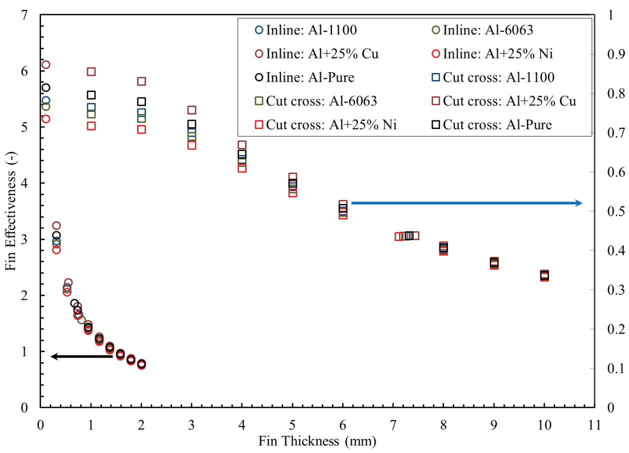

Figure 3. Effect of fin thickness on the fin effectiveness of inline and cross-cut fin heat sink.

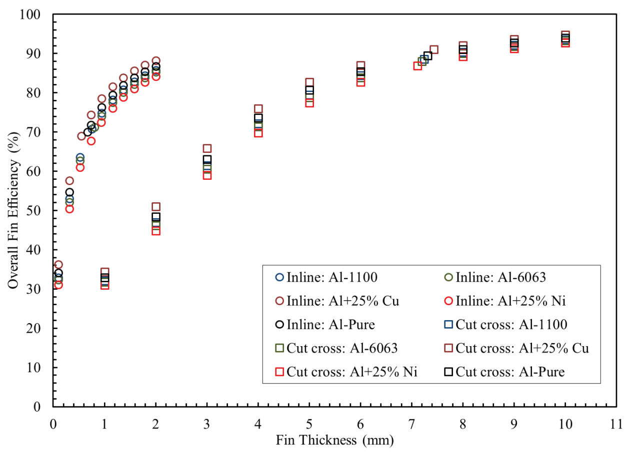

Figure 4. Effect of the fin thickness on the overall fin efficiency for the inline and crosscut fin heat sink.

Al 1100, Al 6063, and Al-Pure is higher than that of the cut cross heat sink by 45.6%, 38.1%, 34.8%, 35.9%, and 32.7% respectively. These behaviours were consistent with previous studies presented by [29] and [31].

The fin efficiency of the heat sink plays role in the performance of the heat, which directly influences the heat dissipation rate from the sink. Figure 4 shows fin efficiency for both inline and cut cross heat sink concerning fin thickness under using four different alloys and aluminium. It can be seen that as the fin thickness increases, the fin efficiency of the heat sink increases for all types of heat sinks. This is because of the increase in the surface area with an increase in the fin thickness that led to more heat can be transferred to the environment due to the increased heat exchange area.

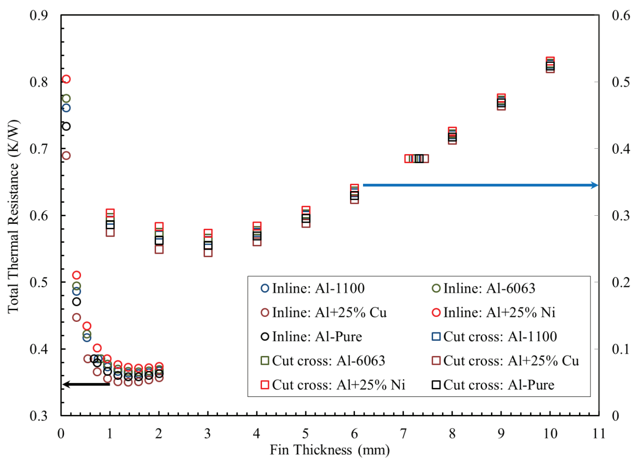

Figure 5. Effect of fin thickness on the total thermal resistance for the inline and cross-cut fin heat sink.

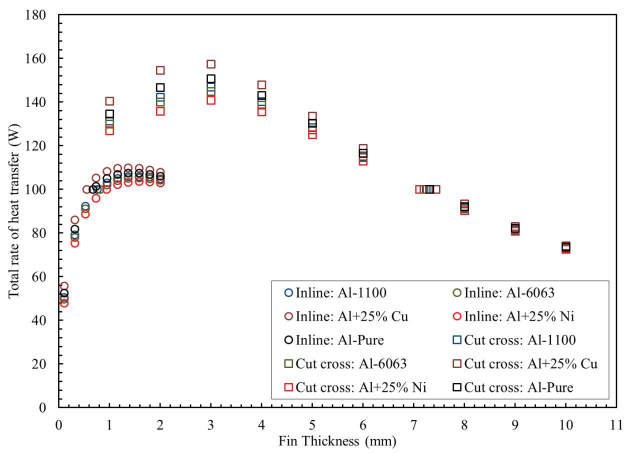

Figure 6. Effect of fin thickness on the total rate of the heat of inline and cross-cut pin fin heat sinks.

Figure 4 also shows that the fin efficiency of the inline heat sink is higher than that of the cut cross heat sink at a fin thickness of less than 2 mm. In contrast, the fin efficiency of the cut cross type is larger than the inline type when the fin thickness is greater than 6 mm. It can be observed that the fin efficiency of the Al-25%Cu, Al- 25%Ni, Al 1100, Al 6063, and Al-Pure of heat sink for the inline sink is greater than that of the cut cross as 27.4%, 37.5%, 34.8%, 35.7%, and 33% respectively at 2 mm thickness. The reason for the trend due to the increase in the surface area of heat transfer for the in-line is greater than that of the cut cross for a small size. In addition, the results show that the fin efficiency of the heat sink using Al- 25%Cu has the highest value while the lowest value of the fin efficiency was observed for pure aluminum. Moreover, the heat sink using Al- 25%Ni, Al 1100, and Al 6063 has moderate values. This behavior can be attributed to the values of thermal conductivity, which increases with adding copper, and Nickel to the aluminum because the thermal conductivity of the copper and nickel is greater than that of the aluminum. Consequently, the thermal conductivity of the heat sink with Al- 25%Cu is higher than that of Al- 25%Ni, Al 1100, and Al 6063. Similar behaviour was observed in the previous study that is introduced by [15, 29-31].

The main parameter of the heat sink performance is thermal resistance influences the overall heat transfer rate. Figure 5 introduces the thermal resistance system as a function of the fin thickness of the inline and cut cross-heat sink for various types of alloys. As can be noticed, the thermal resistance decreases as the fin thickness increases to the minimum value before it stables, and then rises with rise in the fin thickness. This is because of the increase in the fin volume as the fin thickness increases. It can also be observed that the thermal resistance of the inline heat sink is lower than that of the cut cross heat sink. This can be explained due to the increase in the volume of the heat sink by using a cut cross heat sink compare with the inline heat sink. For the effect of using alloys instead of pure aluminium, the thermal resistance of the Al- 25%Cu heat sink is lower than that of the Al- 25%Ni, Al 1100, and Al 606 respectively. For instance, the thermal resistance of the inline heat sink using Al- 25%Cu is less than that of the Al 6063 at 4.3%. While thermal resistance of the cut cross heat sinks using Al- 25%Cu is little than that of the Al 6063 by 6.7%. This behaviour was agreement with previous studies such as [7, 15, 19, 27, 32].

The heat-dissipated rate to the environment is one of the parameters in the evaluation of the performance of the heat sink. Figure 6 shows the heat-dissipated rate as a function of the fin thickness for both inline and cut cross heat sink under different alloys. It can be seen from this figure, the rate of heat-dissipated from the cut cross heat sink increases as the fin thickness increases until reaches maximum value before it reduces with an increase in the fin thickness. While for the inline heat sink the heat transfer rate increases as the fin thickness increase before stables at 2 mm approximately. The main reason for this trend is that the surface area increases with an increase in the fin thickness. On the other hand, the reduce in the heat loss of the cut cross heat sink, which starts after 2.5 mm fin thickness, can be explained to the rise in the pressure drop, i.e., a reduce in the mass flow rate. In terms of the heat sink configuration, it can be observed that the cut cross heat sink has the highest value rate of heat transfer compared with the inline heat sink type. This is because more heat can be transferred to the environment as the surface exchange area increases for the cut cross heat sink compared to the inline heat sink.

For the alloy type, it can be observed that heat dissipated from Al- 25%Cu heat sink was higher than that of Al-Pure, Al- 25%Ni, Al 1100, and Al 6063 rate of heat transfer. For example, the heat transferred increased by 7.3%, 4.4%,

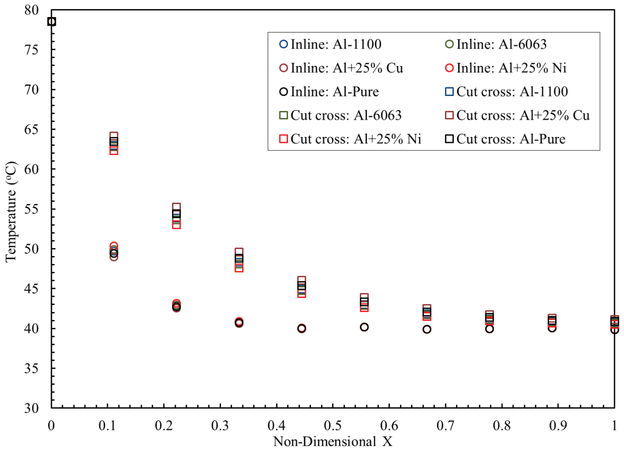

Figure 7. Temperatures distribution along one fin with the non-dimensional length $\bar{x}$ for inline and cross-cut pin fin heat sinks.

2.6%, and 1.8% by using Al- 25%Cu, Al-pure, Al 1100, and Al 6063 respectively compared to Al- 25%Ni for the cut cross heat sink. While it increases by 8.4%, 5.6%, 3.1%, and 2.2% for the inline heat sink. This can be attributed to the fact the thermal conductivity of the Al- 25%Cu heat sink is higher than that of Al 6063Al which leads to giving more heat capacity compared to Al 6063Al. In addition, the thermal conductivity of Al- 25%Ni and Al 1100 is greater than Al 6063Al. Consequently, the heat dissipated by the heat sink using Al- 25%Ni and Al 1100 was also greater than that of Al 6063Al. Similar behaviour was introduced by [5] and [3, 7, 15, 19, 24, 32].

Figure 7 shows the temperature curve for all the heat sink types along the length of the fin. It can be seen that from the Figure the temperature decreases along the fin length before it stables. Moreover, for both inline and cut cross heat sink, the temperature using Al- 25%Cu, Al- Pure, Al 1100, and Al 6063 is greater than that of the Al- 25%Ni.

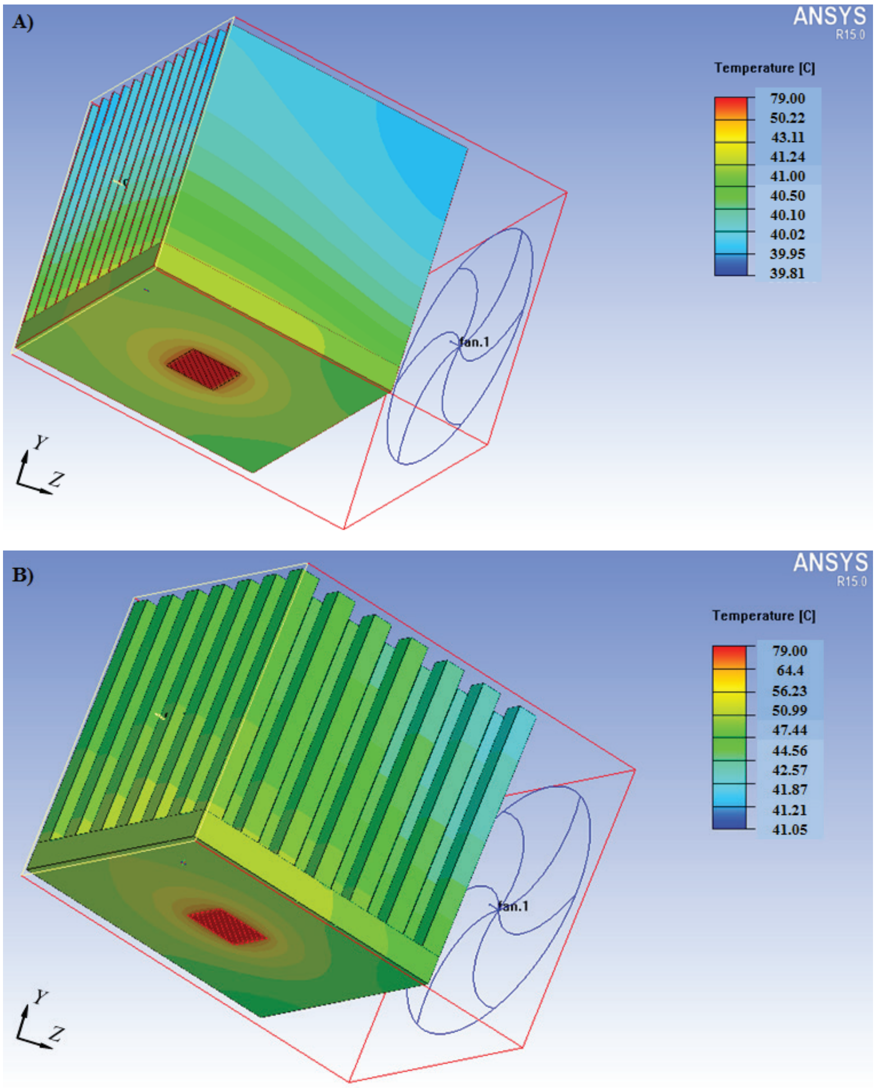

Figure 8. Orientation Temperature contour for (a) inline (b) Cross-cut pin fins, Al-pure.

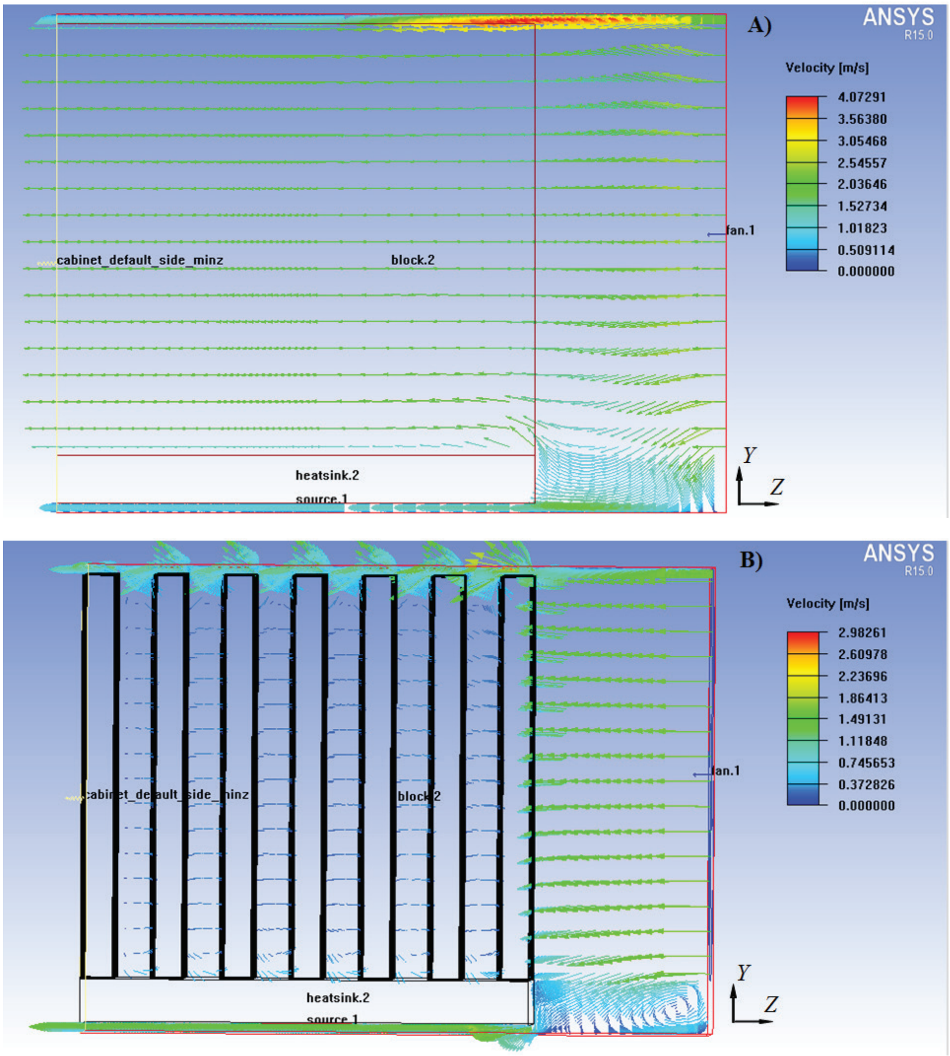

Figure 9. The velocity vector for (a) inline (b) Cross-cut pin fins, Al-pure.

As mentioned previously, this is because the values of thermal conductivity of Al- 25%Cu, Al- Pure, Al 1100, and Al 6063 are greater than that of the Al- 25%Ni heat sink. Also, the results show that the temperature of the cut cross heat sink is higher than that of the inline heat sink. Whereas the temperature of the cut cross heat sink using Al- 25%Cu, Al-Pure, Al 1100, Al 6063, and Al- 25%Ni are greater than that of the inline heat sink as 11.9%, 10.6%, 9.8%, 9.5, and 8.6% respectively. Similar behaviours of temperatures were presented by many studies [33, 14, 19, 32].

Figure 8 also shows the temperature contours for each type of heat sink with the dimensions illustrated in Table 3. The results demonstrated that the temperatures of the cut cross heat sink are higher than the inline heat sink for the same material pure aluminum.

The velocity contours for two types of heat sinks (pure Aluminium) are shown in Figure 9. Thereby, the results illustrated that the air velocity of the cut cross heat sink is lower than the inline heat sink. This is because the airflow has low resistance between the fins for the inline type compared to the cut cross heat sink.

CONCLUSIONS

In this paper, the effect of aluminium alloys on two types of heat sinks has been studied. The main conclusions from this study can be summarized as follows:

1. The effectiveness of the heat sink using Al- 25%Cu has the highest value, which is higher than that of the Al-25%Ni, Al 1100, and Al 6063 of the heat sink respectively. While the lowest value of the fin efficiency was observed for pure aluminum. Moreover, the heat sink using Al- 25%Ni, Al 1100, and Al 6063 has moderate values.
2. The fin efficiency of the inline heat sink is higher than that of the cut cross heat sink at $t_{fin} \leq 2mm$. It can be observed that the fin efficiency of the Al-25%Cu, Al-25%Ni, Al 1100, Al 6063, and Al -Pure of heat sink for

the inline sink is greater than that of the cut cross as 27.4%, 37.5%, 34.8%, 35.7%, and 33% respectively.
3. The rate of heat-dissipated from the cut cross heat sink increases as the fin thickness increases until reaches maximum value before it decreases with an increase in the fin thickness. While for the inline heat sink, the heat transfer increases as the fin thickness increase before stables at 2 mm approximately.
4. Al- 25%Cu cut cross heat sink gives the highest performance compared with other types of heat sink due to it has the highest thermal conductivity. Moreover, the outcomes of the study indicate that the cut cross heat sink is better than the inline heat sink in terms of performance of the heat sink.
5. Al- 25%Ni alloy heat sink obtains moderate values of the heat sink performance for both inline and cut cross heat sink.
6. It can be extended to study the same topics as an experimental study, which is studied in the work.

NOMENCLATURE

A	Surface area of fins (m^2)
D	Diameter of the pin fin (m)
H	Height the pin fin (m)
h	Heat transfer coefficient ($W/m^2.K$)
K	Thermal conductivity, (W/m. K)
L	Length, (m)
n	Number of fins (-)
Nu	Nusselt number, (-)
P	Perimeter,(m)
Pr	Prandtl number, (-)
Q	Heat transfer rate, (Watt)
R	Thermal resistance, (K/W)
Re	Reynolds number, (-)
S	Space between fins, (m)
T	Temperature, (°C)
t	Thickness, (m)
U	Mean velocity, (m/s)

Greek symbols

γ	Aspect ratio, (-)
e	Effectiveness
η	Efficiency, (%)

Subscripts

a	approach
ai	Air
b	Base
Dh	Hydraulic diameter
f	Fluid
HS	Heat sink
L	Longitudinal
max	maximum
T	Transverse
ΔP	Pressure drop, (Kpa)

Abbreviations

Al	aluminum
Be	Beryllium
CFD	Computational fluid dynamic
Cu	Copper
EES	Engineering equation solver

ACKNOWLEDGEMENTS

The authors wish to appreciate the college of engineering at Tikrit University for its support to complete this research.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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