City University eJournal of Academic Research (CUeJAR)
e-ISSN : 2682-910X
CUeJAR Homepage: https://www.city.edu.my/CUeJAR

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Optimisation of Cooling Plate's Channel Design on the Channel size and The Influence Toward The Convective Heat Transfer Coefficient

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Abstract

Heat removal has been one of the major concerns in Proton Exchange Membrane Fuel Cell (PEMFC) since excessive accumulation of heat could reduce the performance of stack and diminish the lifespan of the membrane and catalyst of PEMFC. ***.*** *The parameter, cooling plate will have an effect on PEMFC longevity and efficiency as height and width of the channel has an influence towards pumping power, thermal resistance, pressure drop and heat flux. The aim of this research is to improve the effect of heat transfer in the cooling system of PEMFC through a feasibility study of cooling plate's channel design. The cooling plate performance was investigated through simulation by using ANSYS. The geometry modification on the original PEMFC cooling plate was suggested to analyse and compare the heat transfer performance for several geometry variations focusing on the height and width of the cooling plate's channel. Throughout the finding from this research, as the size of channel was smaller, the velocity of heat transfer and transmission was higher which increased the convective heat transfer coefficient which resulted in lower outlet temperature of the cooling plate's channel.*

1. Introduction

Global warming is one of the uprising issues that worries and gives a huge impact on mankind. One of the alternatives on countering this issue is by providing environmentally friendly and reliable energy supplies which are essential for sustainability of life. Proton Exchange Membrane Fuel Cell (PEMFC) are one of the alternatives in the automotive industry on reducing carbon release which was the major influence to global warming. PEMFC are known for using fuel cell technology or hydrogen technology which utilise the ionisation of hydrogen and oxygen to produce electricity. It is apparent that fuel cells and hydrogen can fulfil the increasing needs of societal growth and have the potential to address the sustainability and efficiency issues in energy fields. In PEMFC, chemical energy is converted to electrical energy through a chemical reaction between hydrogen and oxygen (Bargal et al., 2020). Oxygen will

CUeJAR
Received: 17th October 2022
Revised: 15th November 2022
Accepted: 5th December 2022

be used for electricity on generating engines and water vapour will be released which are harmful to the environment.

The PEMFC has been chosen as a power generator especially in electric vehicles because it is more sustainable as compared with the traditional fuel combustion system. Among the key benefits of PEMFC is its high responsiveness and efficiency to load adjustments, small design, lightweight, extended life, and large current density (He et al., 2018). PEMFC is renowned for its capacity to start up quickly at low operating temperatures of between 60 and 80 degrees Celsius for Low-Temperature PEMFC (LT-PEMFC). While, in high operating temperature, it has the ability on start up in between 100℃ to 200 (HT-PMFC)(Chandan et al., 2013; Islam et al., 2015). Both types are relatively having lower operating temperatures compared to the conventional type combustion engine. Although PEMFC is known to have a lot of advantages, there are some concerns of PEMFC which is on the heat removal. This is one of the primary concerns in PEMFC because excessive accumulation of heat could reduce the performance of fuel cell stack and diminish the lifespan of the membrane and catalyst (Bvumbe et al., 2016).

The parameter of a cooling plate will have an effect on PEMFC longevity and efficiency as height and width of the channel has an influence towards pumping power, thermal resistance, pressure drop and heat flux (Ghasemi et al., 2017; Soupremanien et al., 2012). When increasing the height of the cooling plate channel, the pumping power and heat flux will increase. Height and width of the channel are as shown **in Figure 1.1** which refers to **Table 1.1**. As a result, as the heat flux increased, the fluid's outlet temperature rose. While the thermal resistance and pressure drop will decrease as the channel height rises. Whilst, the increase of the width of the cooling plate channel, the pumping power, heat flux and pressure drop will decrease. While the thermal resistance will increase as the channel height rises. The decrease of the heat flux will also decrease the coolant fluid outlet temperature and this can reduce the performance of the PEMFC (Chen et al., 2021). In order to avoid the pressure drop penalties, a deep and narrow channel performs better in terms of heat transfer than a shallow and wide channel, which can keeping a good equilibrium between pressure decrease and heat flow.

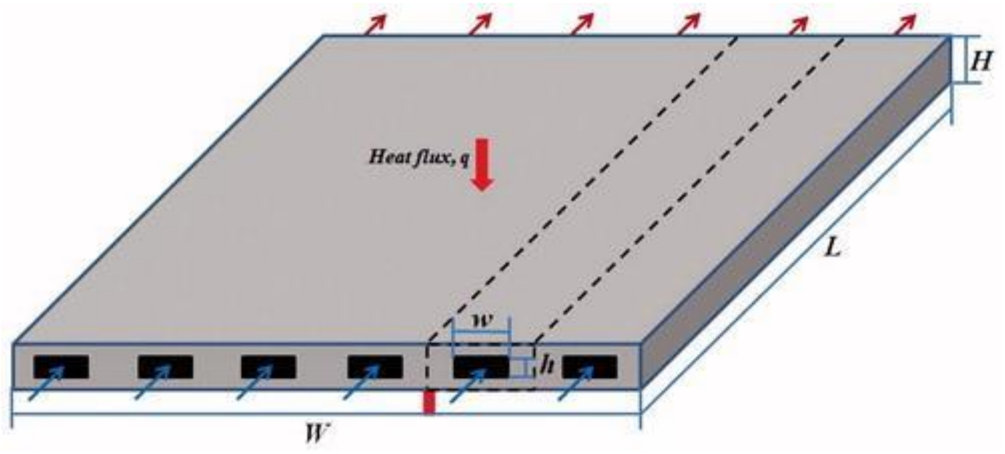

Figure 1.1*: The channel schematic diagram*

Table 1.1*: The table of the symbol and definition*

Symbol	Definition
w	Width of channel
h	Height of channel
W	Width of cold plate
L	Length of cold plate
H	Height of cold plate
q	Heat flux

Thus, the focus of this research is to improve the effect of heat transfer in the cooling system of PEMFC through a feasibility study of cooling plate design. The cooling plate performance was investigated through simulation by using ANSYS. The geometry modification on the original PEMFC cooling plate is suggested to analyse and compare the heat transfer performance for several geometry variations focusing on the height and width of the cooling plate.

2. Methodology

2.1 Design of the serpentine cooling plate's channel

The serpentine design of the cooling plate is chosen in this research as the topology also helps to decrease the danger of flooding in the channel due to forced accumulates water out. As a consequence of its strong performance and reproducibility, the serpentine design has become an industry standard and as a reference design, it may be used to evaluate any improvements or new designs of the flow field pattern which is tested on the fuel cell test performed in order to better understand the effect of channel depth modification on fuel cell performance (Baroutaji et al., 2021; Sauermoser et al., 2020).

The original specification of the cooling plate's channel was 5 mm (W) x 1 mm (H) ; this model will act as the reference model. In order to optimise the cooling plate, 20 total models of the cooling plate's channel have been designed with variation of different parameter. 10 models were designed on different width and another 10 models on different height. Dimensions of models with different width and height are tabulated in **Table 2.1** and **2.2**. The height of the cooling plate is kept constant at 1mm for models with variation of width. While for model with variation of height, the width was kept constant at 1.0mm based on the reference from Zakaria (Zakaria et al., 2016; Zakaria, Mohamed, bin Mamat, Saidur, Azmi, Mamat, & Sainan, 2015; Zakaria, Mohamed, bin Mamat, Saidur, Azmi, Mamat, & Talib, 2015).

Table 2.1: *The dimensions of the 10 models with different width with model 5a act as the reference model*

Model	Width	Height
1a	1.0 mm	1.0 mm
2a	2.0 mm	1.0 mm
3a	3.0 mm	1.0 mm
4a	4.0 mm	1.0 mm
5a	5.0 mm	1.0 mm
6a	6.0 mm	1.0 mm
7a	7.0 mm	1.0 mm
8a	8.0 mm	1.0 mm
9a	9.0 mm	1.0 mm
10a	10.0 mm	1.0 mm

Table 2.2: *The dimensions of the 10 models with different heights with model 1b acted as the reference model.*

Model	Width	Height
1b	5.0 mm	1.0 mm
2b	5.0 mm	2.0 mm
3b	5.0 mm	3.0 mm
4b	5.0 mm	4.0 mm
5b	5.0 mm	5.0 mm
6b	5.0 mm	6.0 mm
7b	5.0 mm	7.0 mm
8b	5.0 mm	8.0 mm
9b	5.0 mm	9.0 mm
10b	5.0 mm	10.0 mm

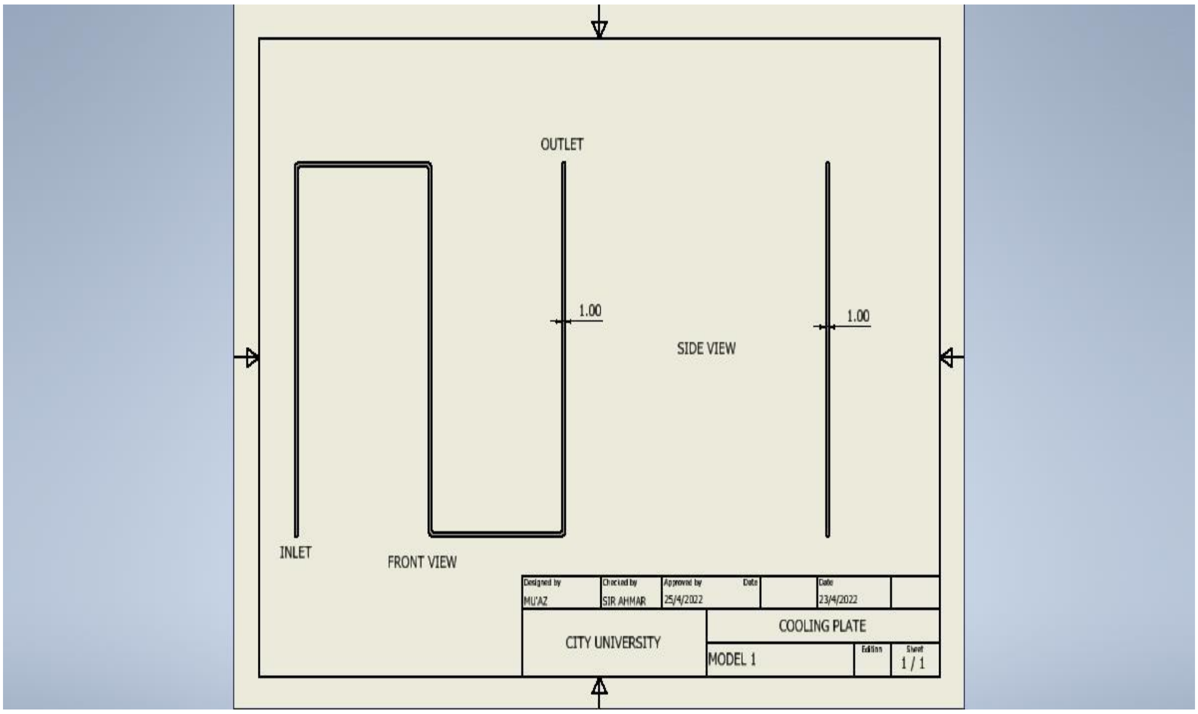

Figure 2.1*: Sample design of the model in which the height and width will change referring to each model dimension. The dimension shown in the front view indicates the width while, dimension shown in the side view indicates the height.*

3. Result and discussion

3.1 Impact of width size to the outlet temperature (heat transfer)

All models were run into ANSYS simulation to monitor the heat flow based on the outlet temperature of each model. From the simulation, the heat profile contour indicates the temperature of the outlet surface of the cooling plate. Model 1a with the smallest width showing outlet temperature of 73.46°C. Next as the width slightly increase in model 2a, the temperature also increases 69.0°C. The model 3a showing the outlet temperature of 69.41°C. Whilst, model 4a showing temperature of 69.5°C. Next, the model 5a having outlet temperature of 69.53°C. Model 6a having outlet temperature of 69.51°C. While model 7a and 8a both having almost similar temperature at the bottom of the outlet surface which is 69.44 and 69.38°C. Lasty, model 9a and 10a resulting to outlet temperature of 69.36°C and 69.33°C accordingly. The result of the outlet temperature on the variation design of width dimension were as plotted in **Figure 3.1**.

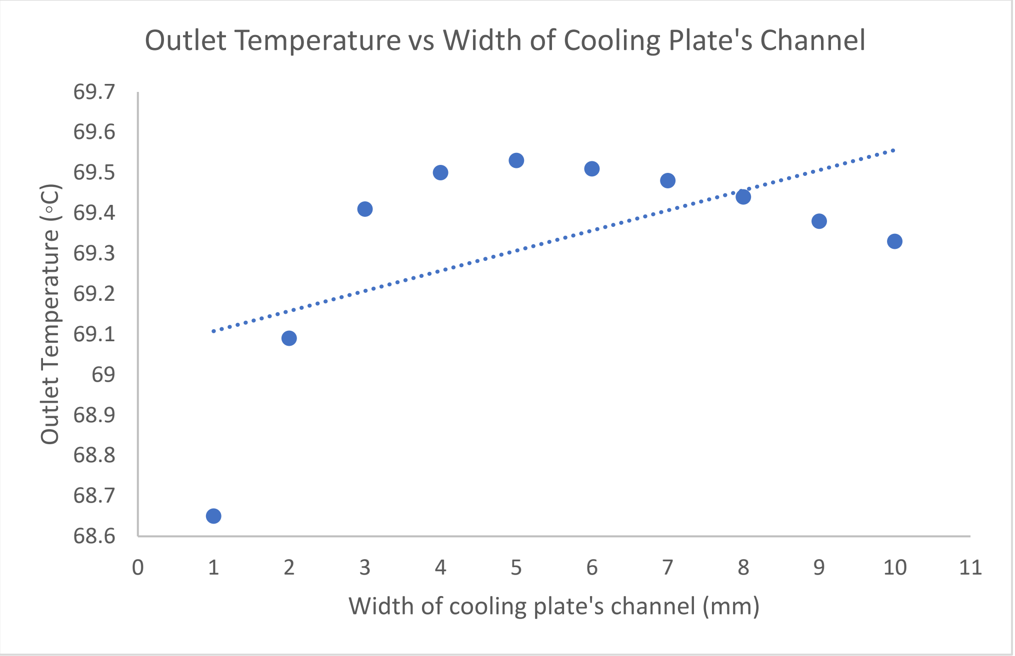

***Figure 3.1**: The graph on the trend of influenced on the width of cooling plate's channel to the outlet temperature of the channel*

Based on the graph in figure 3.1, model with smallest width of channel has a better performance in heat transfer because of the lowest outlet temperature of 68.65 ◦C compared with other models and the original model, which is the model 5a. This is due to the small width of the channel resulting in higher velocity flow. Consequently, the heat transported through the fluid evacuated faster from input to output of the cooling plate. As the width increases, more heat is absorbed, and velocity of the heat flow decreases. Thus, based on the obtained trends, it can be said, as the width of the cooling plate's channel wider, the outlet temperature will increase as well due to the velocity of heat transfer through the outlet of the channel.

3.2 Impact of Height to the outlet temperature (heat transfer)

As for models with different heights, the outlet temperature of each channel was described from the upper section of the outlet. Model 1b with the shortest height the outlet temperature shown 69.53°C. The model 2b with slightly increase height having the outlet temperature of 67.48°C. The outlet temperature of model 3b dropped to 66.37°C while starting from model 4b temperature at the outlet increased to 74.82°C. The model 5b and 6b having almost similar outlet temperature of 75.48°C and 75.84°C accordingly. The outlet temperature increases to 76.14°C for model 7b. Next for model 8b, the outlet temperature is 76.37°C. Whilst for model

9b having outlet temperature of 76.53°C and lastly for model 10b having highest outlet temperature of 76.67°C. The results on the outlet temperature were plotted as in **Figure 3.2**.

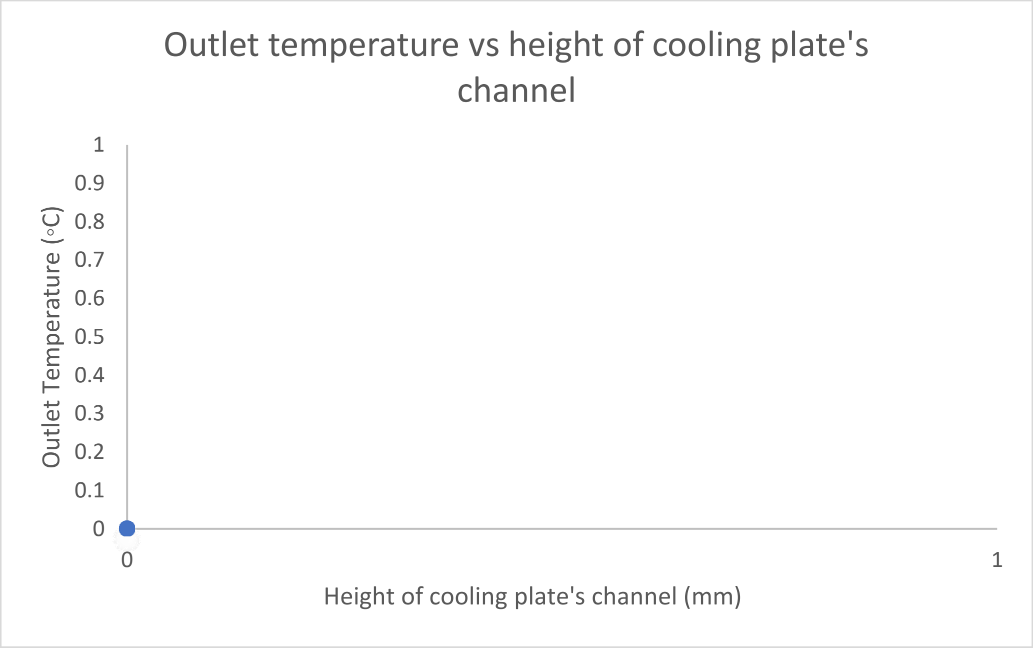

Figure 3.2: *The graph on the trend of influenced on the width of cooling plate's channel to the outlet temperature of the channel*

From figure 3.1, the trend shown as the height of the cooling plate's channel increases, the outlet temperature also increases. However, from the results obtained, model 3b has optimum performance heat transfer with the lowest outlet temperature compared with other models and the original model, which is the model 1b. The results reveal that the height difference between the models has an impact on the outlet temperature. The reason for this finding is due to the heat flow in the channel, as the size of channel increases, lower rate of heat flow and slower velocity of heat move from inlet to outlet which result in temperature risers in the outlet of channel.

In both simulations with variation of height and width, the inlet temperature is set at 60 °C while the heater surface temperature is set at 80 °C. As a result, the outlet temperature obtained is also within the range of 60°C to 80°C. This fulfil the PEMFC's operating temperature range as the low operating temperature (< 60°C) will result to cathode flooding and higher operating temperature (> 80°C) will lead to dryness of membrane (Azmin et al., 2020; Chen et al., 2021; Kandlikar & Lu, 2009; Li & Sundén, 2018)

3.3 Heat Transfer Comparison

Based on the outlet temperature and variation of width and height, the convective heat transfer coefficients were obtained and plotted into graphs in **Figure 3.3** and **Figure 3.4** for variation of different width and height accordingly. Based on the width of the cooling plate's channel, model 5a shows the lowest value of convective heat transfer as the model with 5mm width of channel having the lowest value of convective heat transfer of 1789.82 W/m^{2}K compared to other models. However, based on the plotting trend, the width of the cooling plate's channel shows influence towards the convective heat transfer. As the width of the channel reduces which results in higher outlet temperature thus influenced to declining of convective heat transfer value. Therefore, out of all 10 models, model 1a represents the most optimal width dimension as it is showing the highest value of convective heat transfer coefficient value of 1828.17 W/m^{2}K. As for the variation of height graph in **Figure 3.4**, model 10b with the largest value of height is having the lowest value of convective heat transfer coefficient of 204.63 W/m^{2}K. while the highest convective heat transfer coefficient was obtained from model 3b with value of 2677.69 W/m^{2}K. Thus, similar to the trend from variation of width, for variation of height, it was shown that as the height of the channel increases, the convective heat transfer coefficient would reduce. As a consequence, one general conclusion can be made from the graph, as the dimension of cooling plate's channel smaller, the convective heat transfer coefficient value higher which significantly show that the model having better the heat transmission due to higher motion (velocity) which result to higher transfer rate from the small dimension of the channel (Huang et al., 2020; Tang et al., 2015).

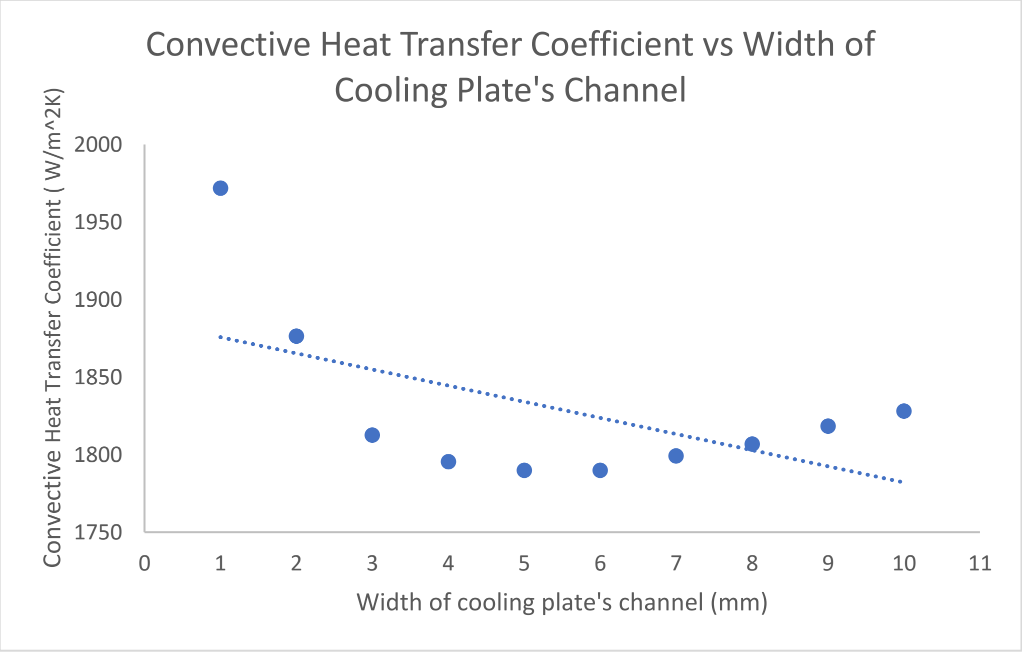

Figure 3.3*: The graph on the trend of influenced on the width of cooling plate's channel to the convective heat transfer coefficient*

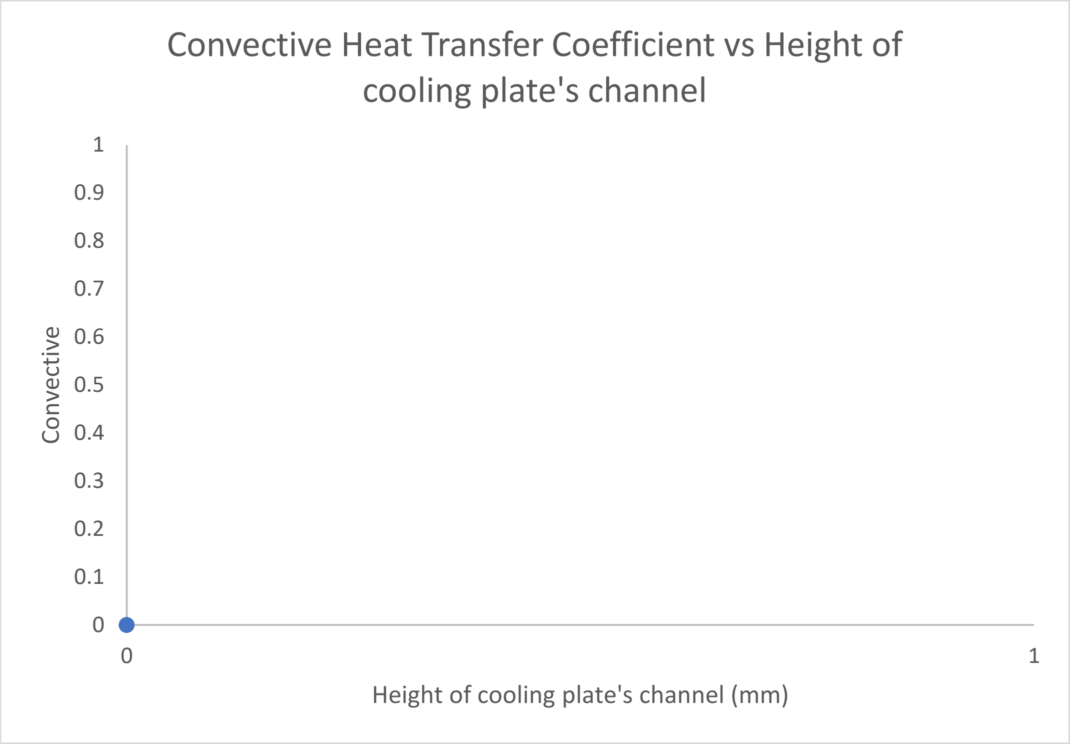

Figure 3.4*: The graph on the trend of influenced on the height of cooling plate's channel to the convective heat transfer coefficient*

4. Conclusion

As per the study, a deep and narrow channel performs better in terms of heat transfer than a shallow and wide channel. Therefore, model 1a, which has a narrow width, and shorter height has a better performance in convective heat transfer coefficient than other models with bigger dimension. Generally, the justification of this finding is due to the velocity of heat transfer from inlet to outlet, as size of channel are smaller, the velocity of heat transfer and transmission are higher in which increase the convective heat transfer coefficient which result to lower outlet temperature of the cooling plate's channel. Few recommendations to improve on this research are by using higher concentration nanofluid compared to water or using different variations of cooling plate design such as parallel or distributor cooling plate. These two recommendations will influence the thermal conductivity which will improve the convective heat transfer.

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