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An Experimental and Numerical Study the Performance of Finned liquid Cold-Plate with Different Operating Conditions

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***Abstract*- The temperature is the most important thing that limits the electronic devices applications around the world. All of them need to be cooled under particular temperature to be safe. During the history there are many applications have been used for this purpose, such as cold-plate, which is considered one of them. One type of these cold-plates has been investigated experimentally and numerically in this study. Experimentally, the finned cold-plate is tested with different values of water flow rates and inlet temperatures. In the numerical study, the STAR CCM+ program is used by depending on the values of water flow rates and inlet temperatures in experimental tests. A comparison between these two approaches has been made.**

According to the results, there is agreement between experimental data and numerical solution. Also, the flow rate effect gives that, it has a slight effect on fin temperature gradient, where the average change in cold-plate base temperature does not overstep 2%. In addition to fin temperature distribution, water inlet flow rates affect the water temperature along its slot, it can be noticed that decreasing rate of water temperature has inversely proportional with water flow rate. In-spite of this proportional, the turbulent flow rate leads to dissipated more energy than laminar flow rate, but the problem should be encountered is that pressure drop might be duplicated through this turn of flow rate. Furthermore, the average change of dissipated power within laminar or turbulent state only is not considerable.

***Keywords*-** Liquid cold-plate, Fins, Natural convection, Convection heat transfer.

I. INTRODUCTION

These days the using of liquid cold plates is growing more and more, because the huge number of electronics applications used around us that need to high performance coolers. In order to improve their performance or increase the power dissipated, many types of cold plates are used. In addition many researchers have tried to improve, and optimize them.

In one of these studies [1] three different designs of cold plates are made and tested to investigate parameters that affect the heat transfer rate. One of these factors is flow pattern and coolant velocity. Hence, three types of cold-plates are investigated in this study, double spiral channels, swirling flow channel type A, and swirling flow channel type B. All of these types are compared with a local brand cold-plate (Tai-Chi water cold-plate) in order to determine the degree of improvement. The most important results of this study are that. First of all, the performance of simple flow channel of Tai-Chi cold-plate is better than the double spiral channel cold-plate, because the contact area is greater. Also, higher heat transfer rate can be got by increasing flow rate, but that will shorten the contact time between the coolant and plate. Another result can be noticed is that, spray of water that causes from going the water through a narrow gap and into the flow-collecting cavity can cause phase change and then take dissipate more heat away.

Six cooling plates that used to cool the polymer electrolyte fuel cell (PEFC) are designed with different forms of flow rate streams [2]. Models 2 and 3 is modified according to model 1 which is serpentine, while model 4 is parallel configuration which has modified in models 5, and 6. According to the results, the performance of models 4, and 5 was lower than that of model 6, while models 3 and 6 have higher cooling performance than both serpentine type models and parallel type model. Model 3 is better than model 6, but the pressure drop in model 3 is higher than the pressure drop in model 6, because in last model there many bends and higher velocity than model 3.

Theoretical and numerical methods are presented by Maddipati *et. al* [3] on thermal design and analysis of cold-plate with different percentage of Ethylen Glycol Water(EGW) solution in order to cool high power dissipating travelling wave Tube(TWT). That is used in electronic warfare (EW) systems for high power applications. The proper percentage of EGW with right value of flow rate play rule to cool the TWT. According to the theoretical results the for 6 LPM flow rate, and 25% EGW has increasing in thermal performance better than 30%, 40%, and 50% of EGW by 3.4%,12.2%, and 23.4%, respectively. These percentages of EGW are simulated in CFD software for fixed mass flow rate for each case. Numerical results show the effect of different percentages of EGW and flow rate on the temperature of TWT. These results clear the maximum and minimum of TWT temperatures and pressure drops.

Some researchers try to design new cold plate like[4], who designed three variants of tangential inlet swirl flow cold plates for liquid cooling of a Luminous CBT 90-Series Phlatlight light. Plates are constructed experimentally, which are studied numerically by CFD simulations in order to determine the perfect according to three variables, convection heat transfer, LED's junction temperature, and pressure drop. According to the results, the inclined inlet cold plate designs give lower LED's junction temperature, and higher convection heat transfer that other cold plate designs at the same pressure drop and Reynolds number.

A study on the design and optimization of the liquid cooling plates that is used EV batteries was done [5]. Different fluid channels are designed for this study. In this study, the numerical part was done for all these cooling plates numerically by using CFD simulation and numerical solution by using ANSYS FLUENT software. According to the results, the cooling plates can acquire good temperature range, although there is need to more efforts to reduce pressure drop.

In [6], it is tried to get the best design of cold plate used in defense power electronics. This study worked to improve thermal resistance, heat transfer rate, and material's (its weight). IGBT cooling plate is analyzed by using CFD software program (Solid work flow), and the best design is evaluated according to better temperature distribution, and more heat transfer rate. The maximum junction temperature is 85 ^{o}C, and the best cooling plate design that gives less junction temperature. Three profiles of channels are carried out in simulation keeping inlet and outlet diameters constant, and a comparison between their results is done in order to achieve the best design.

In this study fin cold plate investigates in order to study some influent parameters. The study divides in two parts, experimentally in order to take the data, and numerically by using STAR CCM+, in order to achieve the optimal operating conditions that achieve the best performance of the cold plate.

II. EXPERIMENTAL PART

In this part, specific finned cold plat is tested with different flow rates and inlet temperatures, and the results tabulated in order to compare them with theoretical and numerical solutions. The cold plate is shown infig.1 and the details of liquid and solid sides are listed in tables I and II.

Fig.1 Aluminum finned cold plate used in this study

Table I
Details of liquid side(Water)

Details	Value
Length of slut(mm)	380
Hydraulic diameter(mm)	90
Inlet temp (K)	380
Outlet temp. (K)	360
Inlet velocity (m/s)	0.4
Outlet pressure(Pa)	10^5
Liquid	Water

Table II
Solid side details(Cold plate)

Length ,(mm)	110
Width, (mm)	110
Total Height (mm)	60
fin length (mm)	50
Number of fins	12
Base thickness	10
Space between fins	5.17
Fin thickness at bottom (mm)	4
Fin thickness at top (mm)	2
Material	AL

The cold plate is connected to tank that includes hot water with electric heater and control system to maintain the water at constant temperature. The water is cooled by cold plate (fig.2). Four variables are measured in the test inlet and outlet temperatures of water, fins temperature gradient, and water flow rate. Fig.2 shows the simple diagram of the devices used in the study.

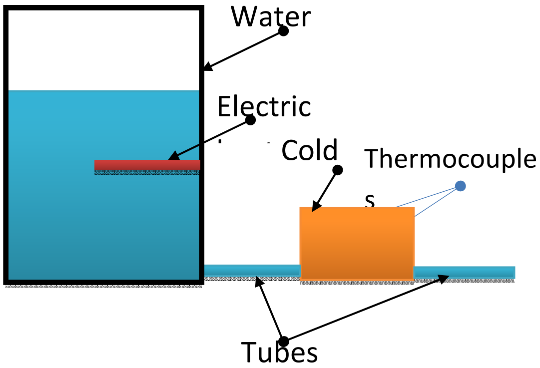


Fig.2 Schematic diagram of the experimental setup

III. NUMERICAL PART

In order to make a simulation of the cold plate, a model is carried out by using STAR CCM+ software program as it is clear in fig.3 which shows the model that used in this study.

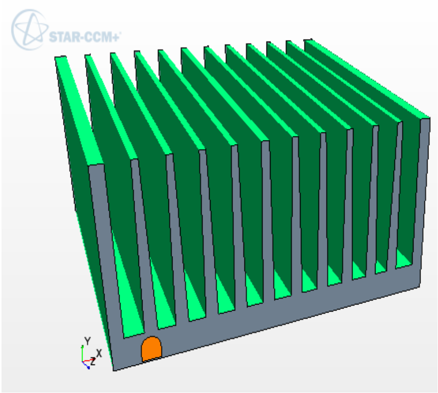
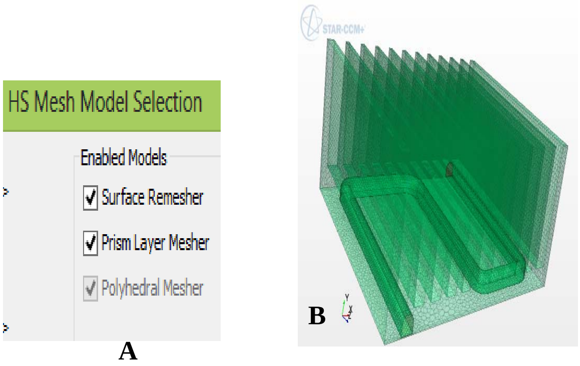


Fig.3 Model of cold plate

The mesh which is used for this model and for all parts is cleared in fig. 4.


HS Mesh Model Selection

Enabled Models

- ☑ Surface Remesher
- ☑ Prism Layer Mesher
- ☑ Polyhedral Mesher

Fig.4 (A)-The mesh model of all parts of the cold plate and (B)-the mesh scene in the STAR CCM+

For this model there are three physical models are applied Air model, solid model (AL), Liquid (Water) model and all of them are shown in fig. 5.


Water

Enabled Models

- ☑ Segregated Fluid Enthalpy
- ☑ Two-Layer All y+ Wall Treatment
- ☑ Realizable K-Epsilon Two-Layer
- ☑ K-Epsilon Turbulence
- ☑ Reynolds-Averaged Navier-Stokes
- ☑ Turbulent
- ☑ Constant Density
- ☑ Gradients
- ☑ Segregated Flow
- ☑ Liquid
- ☑ Steady
- ☑ Three Dimensional

Heat-Sink

Enabled Models

- ☑ Constant Density
- ☑ Gradients
- ☑ Segregated Solid Energy
- ☑ Solid
- ☑ Steady
- ☑ Three Dimensional

Air

Enabled Models

- ☑ Gravity
- ☑ Two-Layer All y+ Wall Treatment
- ☑ Realizable K-Epsilon Two-Layer
- ☑ K-Epsilon Turbulence
- ☑ Reynolds-Averaged Navier-Stokes
- ☑ Turbulent
- ☑ Segregated Fluid Enthalpy
- ☑ Ideal Gas
- ☑ Gradients
- ☑ Segregated Flow
- ☑ Gas
- ☑ Steady
- ☑ Three Dimensional

Fig.5 the physical model for Air, Water, and cold plat material

As it is mentioned above for parameters are measured in experimental test and the same parameters are calculated in STAR +CCM software program and then a comparison between them is made.

First of all numerical model is carried out for different velocities of water and different values of water temperature. The following scenes temperature of cold plate, water temperature, and velocity of Air are explained the sample of the study results. Fig. 6 shows the temperature scene of cold plate (solid). It is clear from the scene the temperature distribution over the cold plate. For instance, the change of temperature in the base of cold plate explains the trace of water flow rate position. Simultaneously, the results show the gradient of temperature along the fins. Temperature gradient of water along its stream is also shown clearly in the fig. 6.

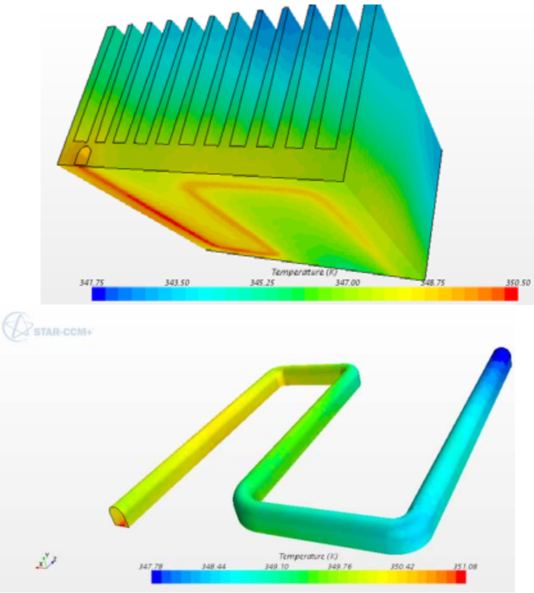


Fig.6 Temperature scenes of Coldplate and Water.

Fig.7 explains the Air velocitydistribution over the cold plate and that because of the buoyancy force.

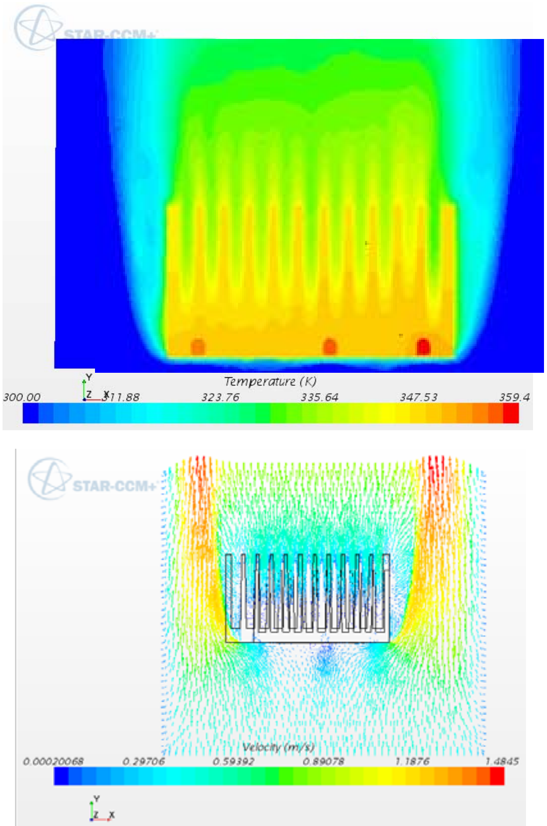


Fig.7 Temperature and velocity scenes of air

Fin temperatures are measured experimentally at 10 positions along mid fin of cold plate and their values are shown in fig.8. Numerically these temperatures are calculated at the same position in order to make a comparison between experimental and numerical values. These temperatures are drawn for six values of the Reynold’s Number from Laminar to Turbulent states.

The difference in temperatures for different values of Reynold’s Number causes due to the amount of energy that transfer through cold plate from the water to the Air. The increasing in dissipated energy leads to increase the temperature of cold plate’s base, and that the main reason for the difference in base temperature of fin.

For instance, the change of Reynold’s Number from 756 to 11353, leads to increase the base temperature of cold plate about 2%. In addition, the gradient of temperature along the final specific Re Number (1513) can decreases to 4%.

On the other hand, the difference between experimental and numerical results has good agreement. For example at Re Number 756 the average difference is around 2.5%.

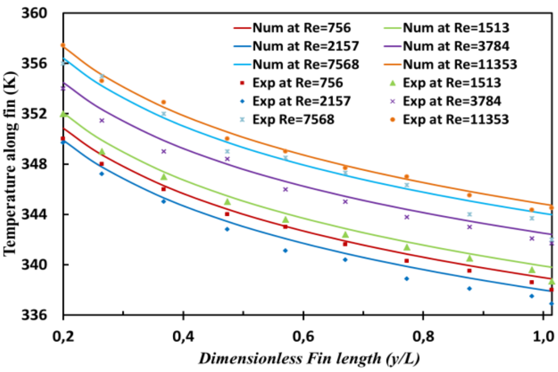


Fig.8 Fin Temperature Distribution with diffirent values of water's Re

The temperature of water decreases along its stream because it loses the heat and this is the main purpose of the cold plate. This decreasing is explained in fig.9. It is clear from the figure that the decreasing rate is proportional with the Re number of water. The maximum decreasing rate occurs at Re 756 while the minimum at the maximum value of Re 11353. Also the figure shows the difference between the experimental measurements and numerical results. The differences are relatively small which equal to 10%, 5%, 2.8%, 3.6%, 4%, and 3% for each value of Re numbers respectively.

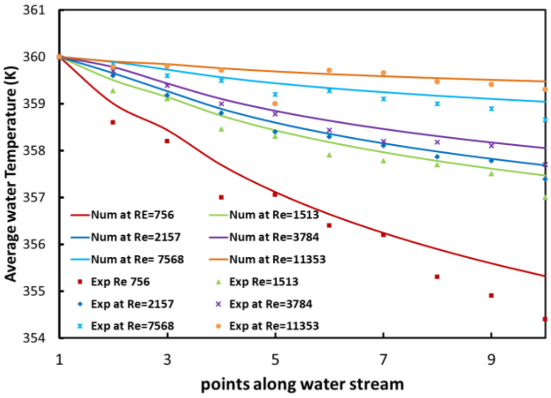


Fig.9 Water Temperature decreasing along water stream

The temperature of water enters the cold plate is constant and equals 360 K and from the outlet temperature of water and its flow rate the amount of energy loses from the water can be determined and that what is explained in figure-10. The figure shows that the amount of dissipated energy in turbulent flow is better than laminar flow. The percentage of dissipated energy increases by 53%,if Re number increases from 756 to 2157, while the temperature difference decreases around 2.5 ^{o}C, therefore this process need to design very deliberately. In addition to the difference between laminar and turbulent, it seems that the increasing in water flow rate will not be useful because the increasing of dissipated energy will be trivial. For instance if Re number increases from 3784 to 7568 the increasing percentage will be equal to 2%.

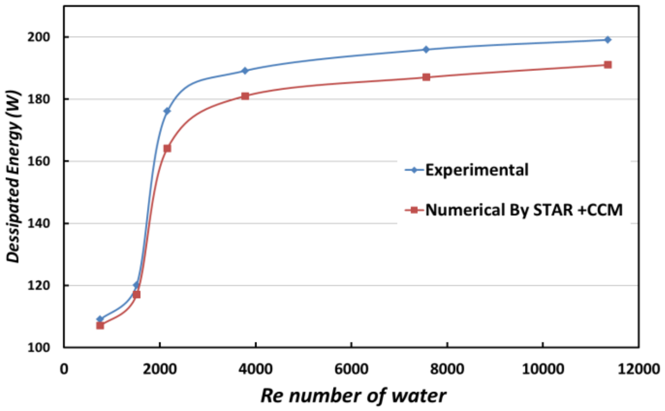


Fig.10 Energy dissipated from Coldplate to the Air for different values of Reynold's Number

The inlet water temperatures are investigated as well, and the results are drawn in fig.11. It can be noticed from the figure that there are relatively matching between the experimental and numerical results, because the deviation is trivial. In addition to the matching of results, the gradient of temperature along the fin decreases with decreasing of water inlet temperature.

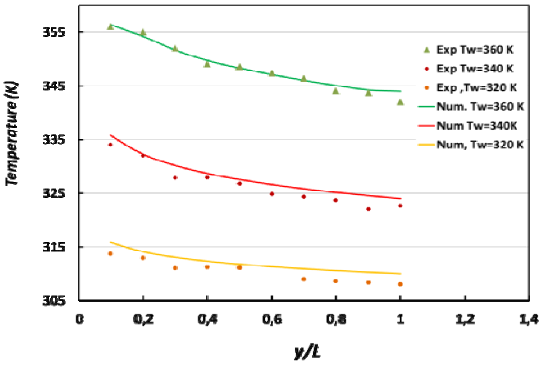


Fig.11 Energy dissipated from Coldplate to the Air for different values of water inlet temp at Re number =7568

Fig.12 explains the effect of water inlet temperature on the amount of dissipated energy. As it is shown, the dissipated power is proportional with the water inlet temperature. That means any rise in water inlet temperature leads to increase the dissipated energy through the cold-plate. If water temperature at inlet increases from 320 K to 340 K, the increasing percent of dissipated energy 95%, and it equals 46% for temperature increasing from 340 to 360K.

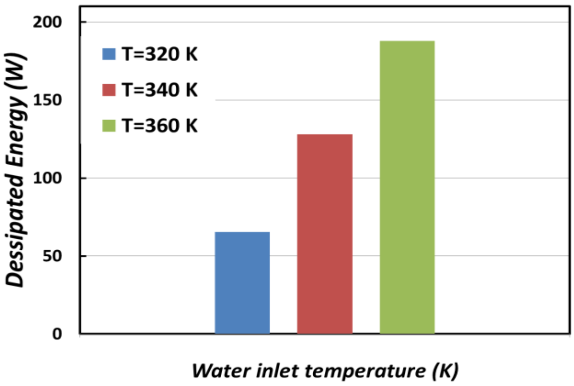


Fig.12 Energy dissipated from Coldplate to the Air for different values of water inlet temp at Re number =7568

Heat transfer is not the only factor that plays a rule in cold-plate design, Pressure drop should be taken in account in such applications. Fig.13 shows that the pressure drop is affected by flow rate or Re number value. It can be noticed that when flow rate changes to turbulent the pressure drop can be duplicated.

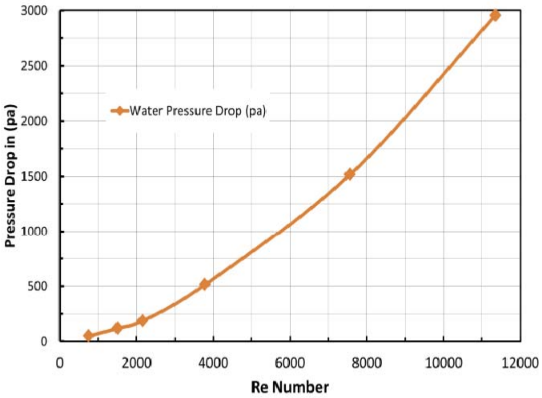


Fig.13 Water Pressure throught the cold=plate for different values water flowrate

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