A review on design and analysis of liquid cooled cold plates using CAD modeling

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Abstract- **For cooling electronic systems new techniques are invented. Cold plate is liquid cooling system used in electronic components. In present work, the modification is done in design of cold plate to reduce its cost and also to increase the heat dissipation rate. Water at various flow rates is supplied for given power inputs and heat removing capacity of each flow rate at that particular heat load is calculated. It is found that water is best working fluid for all flow rates. Methanol and acetone are best suited for high mass flow rates. The cold plate is used to provide a "cold wall" to which individual electronic components are mounted. The design and performance evaluation of a cold plate follows a prescribed procedure that depends on the heat loading and whether the heat loading is on one or two sides of the cold plate. Due to transmission of applied current and voltage sometimes the temperature of the circuit plate goes increasing. This temperature limits the electronic operation. Thus it is necessary to control such temperature, in order to maintain speed of electronic devices.**

Index Terms- Liquid Cooling, Cold Plates, Temperature, Heat Transfer, Electronic Applications.

1. INTRODUCTION

In heavy electronic equipped industries, high temperatures are attained in working conditions. The safe temperature limit for the electronic equipment's 90°C. This raise in temperature will take an adverse effect on the equipment's and sometimes fails at these conditions. This is due to the electronic equipment's life time will be reduced. So the equipment maintain safe temperature condition which is below 90°C, maintain the desired condition liquid cooling is provide effectively. Liquid cooling is a convective heat transfer process.

The cold plates are classified as follows:

1) Formed Tube Cold Plate (FTCP)
2) Deep Drilled Cold Plate (DDCP)
3) Machined channel Cold Plate (MCCP)

Form tube liquid cold plates ensure minimum thermal resistance between the device and the cold plate by placing the coolant tube in direct contact with the device base plate. In this design, copper plate is generally used, although aluminum is sometimes employed in low power applications. In Deep drilled cold plate the heat flux and power dissipation increases, the contact resistance of the plate and the tube wall become unacceptably high. In this design, deep holes are drilled in the plane of the substrate plate. In Machined channel cooling plate, the heat flux increase, it becomes necessary to improve the thermal performance of the channels. In this design, channels are machine-cut into the base plate and a cover is soldered in place to form the flow passages. In the literature thermal analysis of form tube, machined channel and Deep drill cold plates at different working environment has been done. This shows there is a lack of study in the behavior of three different cold plates at same working environment.

In this work the Optimization is achieved by comparing the thermal characteristics of three types of cold plates at same working environment and proposed the best method that can be adopted in different industrial equipment for safe conditions. The Finite Element Analysis and experimental work has been carried out to validate the results. The conclusion has drawn based on the theoretical data and the results from study.

2. NEED OF DEVELOPMENT

The meteoric rise in cooling requirements of commercial computer products has been driven by an exponential increase in microprocessor performance over the last decade. The conventional way to cool microprocessors has been to utilize air to carry the heat away from the chip, and reject it to the ambient. Air cooled heat sinks are the most commonly used air-cooling devices with the highest performers incorporating heat pipes or vapor chambers. Such air cooling techniques are inherently limited with respect to their ability to extract heat from semiconductor devices with high heat fluxes as well as carry heat away from server nodes that have high power densities. Thus, the need to cool future high heat load, high heat flux electronics mandates the development of low thermal resistance and highly energy efficient thermal management techniques, such as liquid cooling using cold plate devices. Liquid cooling of electronics is not a new technology. The need to further increase packaging density and reduce signal delay between communicating circuits led to the development of multichip modules beginning in the late 1970s. The heat flux associated with bipolar circuit technologies steadily increased from the very beginning and really took off in the 1980s. IBM had determined that the most effective way to manage chip temperatures in these systems was through the use of indirect water-cooling. Several other mainframe manufacturers also came to the same conclusion. The decision to switch from bipolar to Complementary Metal Oxide Semiconductor (CMOS) based circuit technology in the early 1990s led to a significant reduction in power dissipation and a return to totally air-cooled machines. However, this was but a brief respite as power and packaging density rapidly increased, matching then exceeding the performance of the earlier bipolar machines. These increased packaging densities and power levels have resulted in unprecedented cooling demands at the package, system and data center levels necessitating a return to water-cooling. So there is need to optimize the design parameters of the cold plate. The work presented here to optimize the outlet temperature of cold water. The result of that is the achievement in maximum heat transfer. The maximum heat transfer can be achieved by increasing more surface area and by supplying cool water or cooling fluid at lower temperature. The study investigates heat transfer through various types of cold plates. All the cold plates have groove for cooling water circulation. The study finds which one is effective comparing with others cold plates.

3. OBJECTIVES OF THE WORK

1) To study the heat transfer phenomenon in cold plates.
2) To obtain the mathematical solution of heat transfer from the cold plates.
3) To make solid model in CATIA V5R19 and find out the finite element analysis solution of cold plates by performing analysis in ANSYS.
4) To find the solution of heat transfer.
5) To compare the model by theoretical and analysis.

4. LITERATURE REVIEW

Ephraim M. Sparrow, states that the work has had two principle foci. The first is the development of a simulation strategy which enables the fluid flow and heat transfer in long, periodic cold plates to be solved by focusing on a single, representative module of the array. This new strategy reduces a highly complex conjugate fluid flow and heat transfer problem to one which is confined to heat conduction in the solid walls of the cold plate. The second focus, which is an application of the new simulation strategy, is to identify heat transfer enhancement techniques which also enable efficient fabrication free from the necessity of using brazing-type manufacturing methods. In particular, the approach adopted here was based on a manufacturing method, friction-stir welding, which yields a highly stable structure capable of withstanding very high pressures. To initialize the design process, it was first decided to use integral fins whose footprint coincided with that of the heat-load sites. It was reasoned that the integral nature of the fins would not only be highly effective in transferring heat but would also provide significant structural support. Computational experiments were then performed to examine the resulting fluid flow pattern in the vicinity of the fins. That assessment revealed the need to take positive steps to direct the flow so as to achieve vigorous contact between the coolant and the surfaces of the fins. To this end, flow-directing baffles were employed.

Matthew V. Horgan, conclude that the Overall, design optimization has been effective in helping obtain an optimum perforated plate design, within a timely manner and with minimized user input. Using an inbuilt automated optimization tool within the CFD software, the user input required in making geometric and meshing alterations was greatly reduced. It is possible that the same conclusions could have been found using a more manual approach, however the time and user input required to do this would have been significantly greater in comparison.

William M. Healy, conclude that the supplement analytical methods in the design of a new Guarded Hot Plate apparatus to measure the thermal conductivity of thermal insulation was ANSYS method. The finite element simulations enabled designers to determine whether heater and coolant tube layouts would generate a uniform temperature profile on surfaces facing the specimen. Analyses also assured designers that one dimensional heat transfer would be present in the meter section of the specimen. The use of ANSYS has provided greater insight into the physics of the apparatus and will enable NIST to make measurements with greater accuracy.

Dupati Ramesh Babu done the design optimization of the cold plates used in defence power electronics. Conjugate Heat Transfer Analysis of the IGBT cooling plate is carried out using the CFD software to document the temperature distribution, velocity of flow and the pressure drop. Design optimization of the cold plate was done to achieve the temperature of less than 85 degrees, which is a design constraint. Optimization is done by changing the profile of flow channels, keeping inlet and outlet diameters constant. Three such iterations have been performed and the results are compared. From the results that the maximum temperature of 370 K (97°C), 368 (95°C) and 354 (81°C) is observed for original, modified model-1 and modified model-2 respectively. Hence it is concluded that the modified model-2 is the best design of cold plate to maintain the temperature within the design limits.

Satish G. Kandlikar gives a brief overview of liquid cooled cold plates. Based on the current practice, a classification scheme is introduced to identify cold plate types. Liquid cooling of high-power electronic devices requires unique solutions, a few of which have been presented in this article. Each task has its own target temperatures and design constraints, which provide challenges for the thermal designers. Some of the thermal design issues, manufacturing constraints, and cost considerations have been presented. A decision tree of design choices is outlined in the process for arriving at an optimum design. The inclusion of a thermal engineer at the outset of a new or upgraded project will result in the best design at the least cost.

Priyanka G, M. R. Nagraj studied the shell and finned tube heat exchanger computationally using ANSYS fluent 13.0. The geometric modeling of the shell and tube heat exchanger is done by using ANSYS design modeler. And CFD meshing is carried out using ANSYS meshing. The analysis is carried out and pressure drop and temperature rise along the tube surfaces has been investigated. Based on the obtained result it can be concluded as follows; Temperature variation with same velocity for castor oil and water is greatly noticeable .This is due to better thermal properties of castor oil than the water. Better effectiveness can be achieved by using castor oil as heat transfer fluid .The effectiveness of the finned tube heat exchanger is quite comparable with other conventional heat exchanger. Energy extraction rate is also quite significant that means a sufficient amount of heat can be recovered by using the finned tube heat exchanger.

Yasamin Khanjari studied the current study aims to consider the performance of a liquid-based PV/T system by a numerical investigation. An attempt is being made in this paper to numerically analyze the liquid cooled PV/T system using the CFD method. In the present work, a 3D model of a simplified PV/T system including water tube and absorber plate is simulated to provide a comprehensive thermal analysis. For obtaining the numerical results, the conjugate heat transfer analysis methodology was applied. The effects of varying the inlet water temperature and absorbed solar radiation are considered. The temperature distribution through the absorber plate and the outlet water temperature are evaluated in form of temperature contours. The measured data attained by the CFD simulations were compared with experimental results in the literature. The numerical simulation results are in good agreement with the experimental measurements in the literature.

Lakshya Garg found that with increase in velocity of cold air, the temperatures of the hot air decreases due to increase in the heat transfer coefficient. The maximum decrease of 4.78% has been obtained in outlet temperature, whereas an increase of 72.39% is observed in pressure drop, when velocity was increased from 14 m/s to 20 m/s. So, 14 m/s cold air inlet velocity was found optimum for operation of heat exchanger. Results obtained from MATLAB program has shown close agreement with the CFD simulation 14 results for different cold air inlet velocities. It is found the change in location of baffles does not affect much to the outlet temperatures of hot and cold air. The addition of three more tubes has resulted in decrease of outlet temperatures of hot air as well as in pressure drop cold air without having much effect on hot air pressure drop. This is due to increase in area and time available for heat transfer. From the velocity distribution, it has been seen that hot air moves from one section to another section of heat exchanger, due to which some area of heat exchanger faces starvation of air near the vicinity of internal baffles. This vacant region is maximum in case of baffle change design.

Shakuntala Ojha studied the theoretical analysis performed, provides a fundamental understanding of the combined flow and conjugate convection-conduction heat transfer in the three-dimensional microchannel heat sink. The model formulation is general and only a few simplifying assumptions are made. Therefore, the results of the analysis as well as the conclusions can be considered as quite general and applicable to any three-dimensional conjugate heat transfer problem. A three-dimensional rectangular microchannel model consists of a 10 mm long silicon substrate with 57 µm wide and 180 µm deep developed using incompressible laminar Navier-Stokes equations of motion is capable of predicting correctly the flow and conjugate heat transfer in the microchannel heat sink. It has been validated using numerical data reported in the literature and a good agreement has been found between the model prediction and measurements. The combined conduction– convection heat transfer in the microchannel produces very complex three-dimensional heat flow pattern with large, longitudinal, upstream directed heat recirculation zones in the highly conducting silicon substrate, where the fluid and solid are in direct contact. A detailed description of the average heat transfer coefficient, temperature, heat flux and Nusselt number was obtained. General conclusions that stemmed from this analysis are presented, together with a brief recapitulation of some of the important remarks made earlier.

Ying-Feng Pang suggested that the most reliable and well-designed electronic device can malfunction or fail if it overheats. Good thermal design is often paramount in achieving high reliability, low manufacturing cost, small size and a predictable development time. The thermal design must be able to dissipate the maximum amount of 15 power required to maintain operating T junction within limit. Thus, thermal design is an important aspect in the overall production design process to achieve the desired operational and reliability objectives for the product. In this research, we managed to achieve a few goals discussed. Numerical modeling is always the fastest and easiest way of analyzing the thermal performance of electronic systems. However, it is always advisable to validate the method of modeling in order to have certain confidence in the numerical results. To validate the method of performing thermal analysis using I-DEAS, both numerical analysis and experimental work were performed using two discrete power electronics components. Results of adequately meshed numerical models were compared to experiment results. Both the numerical and the experimental results showed a good agreement of within 1.5°C in the temperature distribution. In addition, the margin errors of simulation results were within the margin errors of experimental data.

R. J Haywood studied CFD modelling, in conjunction with CAD geometry development and automated grid generation, has been used to model the geometrically complex flow system in a modern ESP. The modelling was used to optimise the flow patterns within two ESP's as much as possible within the given constraints, such that further modification or set-up was not necessary following commissioning. The performance of the two ESP's continues to meet expectations. From a CFD modelling perspective the use of subdomain momentum loss models for these kinds of systems has considerable advantage. Unfortunately, the current work has been unable to provide guidance in the degree of anisotropy that the GDP momentum losses are likely to exhibit, and further investigation is required in this regard.

5. CONCLUSION

Electronics cooling research has been largely focused on high heat flux removal from computer chips in the recent years. However, the equally important field of high-power electronic devices has been experiencing a major paradigm shift from air cooling to liquid cooling over the last decade. Various authors have done detailed study about cold plate and its working under various parameters. Also the dependence of cold plate on working fluid, fill ratio and surfactant concentration on heat transmission is studied. A series of literatures is reviewed which includes a brief description of previous works done in this field & also explained the applications of cold plate till date used in electronic devices. The modification is done in design of cold plate to reduce its cost and also to increase the heat dissipation rate. The modified cold plate uses water to remove major part of heat produced and air for minor part by natural or forced convection.

REFERENCES

[1] Encyclopedia of thermal packaging Volume 2, Air and Liquid-Cooled Cold Plates, Jan 2015.

[2] Wenjun Liu, Hauck Torsten and Josef Drobnik, "Effective Thermal Simulation of Power Electronics in Hybrid and Electric Vehicles", World Electric Vehicle Journal Vol. 5 - ISSN 2032-6653, 2012.

[3] Paisarn Naphon, Somchai Wongwises, Songkran Wiriyasart, "On the Thermal Cooling Of Central Processing Unit of the PCs with Vapor Chamber". International Communications in Heat and Mass Transfer 39, 1165–1168, July 2012.

[4] Satish G. Kandlikar and Clifford N. Hayner, "Liquid Cooled Cold Plates for Industrial High-Power Electronic Devices - Thermal Design and Manufacturing Considerations". Heat Transfer Engineering, 30: 12, 918 – 930, June 2010.

[5] Javier A. Narvaez, Hugh Thornburg, Markus P. Rumpfkeil, Robert J. Wilkens, "Computational Modeling of A Microchannel Cold Plate: Pressure, Velocity and Temperature Profiles", International Journal of Heat and Mass Transfer 78 (2014) 90–98, July 2014.

[6] Feng Zhou and Ercan Dede , "A Novel Design of Hybrid Slot Jet and Minichannel Cold Plate for Electronics Cooling", Conference Paper, March 2015, DOI: 10.1109/SEMI-THERM.2015.7100141.

[7] Kanchan M. Kelkar, Suhas V, Patankar, "Analysis and Design of Liquid-Cooling Systems Using Flow Network Modeling (FNM)". International Electronic Packaging Technical Conference and Exhibition July 6-11, July 2003.

[8] Hsiao-Kang Ma, Bo-Ren Chen, Jhong-JhihGao, Cheng-Yao Lin, "Development of an OAPCP - Micropump Liquid Cooling System in A Laptop", International Communications in Heat and Mass Transfer 36, 225–232, Jan 2009.

[9] Y. P. Zhang, X. L. Yu, Q. K. Feng, R.T. Zhang, "Thermal Performance Study of Integrated Cold Plate with Power module", Applied Thermal Engineering 29, 3568–3573, June 2009.

[10] Hsiang-Sheng Huang, Ying - CheWeng, Yu - Wei Chang, Sih - Li Chen, Ming -TsunKe, "Thermoelectric Water-Cooling Device Applied to Electronic Equipment", International Communications in Heat and Mass Transfer 37, 140–146, Sept 2009 .

[11] Uma Ravindra Maddipati, P. Rajendran, and P. Laxminarayana, "Thermal Design and Analysis of Cold Plate with Various Proportions of Ethyl Glycol Water Solutions", International Journal of Advanced Trends in Computer Science and Engineering, Vol.2, No. 6, pages: 22- 25, Nov 2013.

[12] Jung - Shun Chen, Jung - Hua Chou, "Cooling Performance of Flat Plate Heat Pipes With Different Liquid Filling Ratios". International Journal of Heat and Mass Transfer 77, 874–882, June 2014.

[13] P. Sivakumar, P. Srihari, Prof. N. HariBabu, "Optimization of Liquid Cold Plates Using Computational Fluid Dynamics", International Journal of Engineering Trends and Technology (IJETT) – Volume 27 Number 5, September 2015.