Heat Transfer Analysis of Cold Plate

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Abstract: **This project deals with the design optimization of the cold plates used in defense power electronics. The objective of the work is increase heat transfer rates, and use light-weight material. Best Design of the cooling plate was evaluated based on the better temperature distribution and more heat transfer rate of the cooling plate. Electronics and their use commercially combined with the need for better power dissipation and system cooling, has caused the need to come up with better cooling technologies at affordable costs that are viable for commercial packing. It is 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. A detailed study about cold plate and its working under various parameters is studied, like cold plate on working fluid thermocouple range and insulating material. In this cold plate the design is done by to reduce the cost and increase the heat dissipation rate, the modified cold plate can use water to remove major part of heat produced and air for minor part by natural or forced convection. Further experimental setup is performing at atmospheric conditions and heat transferred is calculated for various flow rates and power inputs.**

IndexTerms - **Cooling Technology, Optimization of cold plate, Heat transfer, Computer Processing Unit (CPU)**

I.INTRODUCTION

All electronic devices are very much important in almost all major industrial and military equipment so more efficient cooling system required. In the recent year it has been dramatically shift in cooling high power devices in the past decade. In electronic air cooling has suffered for many low power devices and it is quite difficult to total power dissipation. Liquid cooling is always better than air cooling techniques since it has high specific heat value. In liquid cooling system, heat removed either in sensible or latent heat form i.e. single phase or two phase flow techniques. Cold plates are used to provide cooling for high heat loads. One surface of cold plate is kept contact with heat source surface and other is dissipating heat is either by natural convection or forced convection. The design and performance evaluation of cold plate follows defined procedure that depends on heat loading and whether the heat loading is one side or two side of the cold plate. Electronic cooling, heat flux from microprocessor will be continuously raised so it's a great challenge in a thermal management.

The design of a cold plate involves heat transfer between the walls of the cold plate and the circulating fluid as well as the pumping power expended to overcome fluid friction and to move the coolant fluid through the passages within the cold plate. For a cold plate carrying a high density fluid, the friction loss is relatively small and it is usually not the controlling factor. But when air and other gases are employed it is not uncommon for the cold plate to quickly dissipate its allotted power. The heat flow between the fluid and the confining surfaces in a heat exchanger can be enhanced by increasing the fluid velocity. However, the velocity increase must of necessity because the heat transfer coefficient varies almost directly with the velocity while the friction loss variation is close to the square of the velocity.

First consider the rate equation for the cold plate which is

$$Q = h.A_s.\theta_m \qquad (1)$$

Thus for fixed heat flow and temperature driving force, this become

$$\frac{Q}{\theta_m} = hA_S \qquad (2)$$

Which indicates that the heat flow per unit temperature difference is maximized when the hA product is maximized.

"Fig.1" Simple liquid cold plate [9]

II.LITERATURE SURVEY

Different studied are carried out cold plate and liquid cooling presented, many studies were reported on microprocessor for its thermal managements and power consumption reduction. An effective liquid cooling methodology and types of cold plates were discussed in different papers. The different modification cases were studied for cold plate modeling. The technique of Flow

Network Modeling is described for the analysis of flow distribution and heat transfer in liquid cooling system it described the efficient prediction of the flow rate, pressure temperature in complete liquid-cooling system.

Satish G. Kandlikar and Clifford N. Hayner classified the cold plates; in this article they discussed selection of cold plate type and channel configuration and some of the relevant manufacturing issues. It was recommended that the thermal designer be involved in the early stages during the electrical design and layout of the devices. In deep drilled cold plate the power dissipation increases, the contact resistance of the plate and the tube wall become unacceptably high. Deep holes are drilled in the plane of the substrate plate, generally made of copper. These holes are then configured with end caps (or plugs) to create coolant flow paths through the substrate.

Y. P. Zhang, X. L. Yu, Q. K. Feng et al. proposed a cold plate for cooling of the electronic components with high heat flux and high heat dissipation. The cold-plate structure of S-type with guide plates was introduced to avoid the heat hot concentration and increase the heat transfer area. The experimental results show that the maximum chip temperature of the novel cold plate was approximately 40% lower than those of the conventional cold plate.

Ting Wang, Bo Gu et al. Proposed fifteen structure schemes of the liquid-cooled plate for thermal control of the power control unit (PCU) in fuel cell vehicle (FCV). At the given serpentine channel with inconstant width, pin fin arrays with various configurations were arranged to improve the performance of three heating zones with multiple heat sources. Based on the same setup and boundary conditions, numerical simulations were conducted for different schemes. The solutions were validated by grid independence check and comparison with previous researches. The effect of the fin parameter and also its diameter height is measured

Two dimensionless factors η_H and η_P were quantified to evaluate the heat transfer enhancement and pressure drop augmentation. The dimensionless performance evaluation factor PEF was cited to assess overall performance of the cold plate. Based on three factors mentioned above, cooling performances of three heating zones and the whole plate were compared among all schemes.

J. M. Armengol, C. T. Salinas, J. Xaman, K. A. R. Ismail et al. Made a frost formation model based on a new two-dimensional approach for the growth rate. For modelling is done formation over parallel cold plates, the basic transport equations of mass, energy and momentum had been discretized using the finite volume method in a two dimensional domain in which air and frost were considered. A fixed grid formulation is used to deal with the airefrost moving boundary. An extended domain in the inlet boundary was considered in order to study the frost formation in the leading edge of the plate. The numerical results were validated against experimental data in which frost growth and temperature as a function of time were reported as local values. The model predictions of the frost thickness as a function of time agree with the experimental data within 10% of deviation for the case of intermediate plate temperature.

III.LITERATURE GAP

From literature survey mentioned above, no one ever tried to use heat removing capacity of fluid effectively in single continuous channel. In the present work the flow channel is selected so that it can remove maximum amount of heat. Also two row passage in which lower one has fluid inlet and upper one has outlet is selected for channel. With this modification the heat transfer to fluid is more since fluid is flowing from one portion of thickness twice in cold plate

IV.WORKING

Cold plates used to provide cooling for high heat loads. In the cold plate one surface is in contact with the heat source and other is in contact with forced or natural convection by using surrounding temperature. Also water is flowing through channels of cold plate, its heat removing capacity is much more than convectional air cooling techniques. Different types of cold plate having different working condition and parameters. Generally cold plate is two loop types with inlet fluid and outlet fluid. In the CPU application; operating temperatures are normally in the range of 50 -100^{0}C [3]. At this temperature water is best working fluid because water operating temperature is 100ºc. In cold plate the heat removed by fluid is purely sensible heat and no phase change of working fluid occurs. The flow rate of fluid in cold plate plays important role in heat removal from surface. For high heat flux applications higher flow rates are preferred while for lower heat flux moderate or lower flow rate is used.

4.1 Classification of cold plates

A review of the cold plate are classified for their manufacture reveals that there are several different types they are depends on different configuration depend on size and power dissipation requirement [9]. These cold plates are classified into four major types as follows:

1. Formed Tube Cold Plate
2. Deep Drilled Cold Plate
3. Machined Channel Cold Plates
4. Pocketed Folded-Fin Cold Plates

V.EXPERIMENTAL SETUP

There are several important factors that affect the performance of the cold plate:

1. Working fluid- Depending working temperature proper working fluid is selected. For example for high temperature ranges up to 100ºc deionized water is used and its heat carrying capacity is more than other fluid. While other fluid temperature range 65ºc methyl alcohol

2. Flow rate – It is very important to maintain constant flow rate for very low to high flow rates. Moderate and low flow rates are used for deionized waterside it is capable of removing the given heat load efficiently.

3. Cold plate material - Cold plates are made from materials having high thermal conductivity and low thermal resistances. Copper is most commonly used material for fabrication of cold plate because of its high thermal conductivity value and inertness to most of working fluids compare to the other material like aluminum and MS

4. Dimensions of the Cold plate- Cold plate are square or rectangular box of dimensions as per component to be cooled. For CPU microprocessor (40×40) mm dimension is generally preferred. It is flexible to mount and easy to assemble.

5.1 Fabrication of Heater plate

For heat input, a heater is fabricated with same dimension as cold plate i.e. 40 x 40 mm. A nichrome wire is used as heating material. It is wounded around a 40 × 40 mm mica sheet. Mica sheet is used because it is good conductor of heat and bad conductor of electricity. There are 16 no. of turns of nichrome wire of width 0.2mm around mica sheet. Precaution is taken so that no two wires make contact with each other. Again the top and bottom surfaces are covered with mica sheet and then fixed with Teflon tape. The connections are made at terminals with low resistance single stranded wires. Nichrome has melting point of 1400 ºC, electrical resistivity of $(1 – 1.5) \times 10^{-6}$ Ω.m at room temperature, thermal conductivity of 11.3 $Wm^{-1}K^{-1}$.The input is given at two terminals of heater from rheostat and required temperature is attained by varying the current and voltage.
A computer processor has 53 watt as input power out of which 90% is wasted as heat. Thus by using rheostat the required wattage input is provided. Since,

$$P = V \times I \text{ (watt)} \qquad (3)$$

By adjusting the current and voltage the temperature is measured at given wattage using digital temperature gun.

5.2 Fabrication of Cold plate

Operations done on copper block:
1. Machining: To get the exact shape of the plate i.e. 40x40mm
2. Grinding: To get proper outer dimensions of copper block.
3. Drilling: To drill 4 holes of 3mm diameter in vertical and its depth is 35mm and horizontal drilling is also done for the continuous inner side flow, only inlet and outlet connected to 3mm tube and other holes are closed by screw which means the copper slab is done by continuous inner side flow.
4. Brazing: To interconnect the holes so that they act as a continuous channel by joining the inlet and outlet using copper tubes with appropriate brazing material. The material is having the same coefficient of thermal expansion as copper.
5. Soldering: To nichrome wire soldering is done with the input connection.
6. Flow control: In the tank contain small submersible pump motor (3Watt), its capacity 200L\H and its can supply the continuous flow, piping can be done at inlet and outlet side of tube and flow can be control through flow control valve.

The cold plate is fabricated with modifications in its design. The single channel is completely replaced by the segregated channel of tubes. The working fluid is passed through the tubes. The 40 × 40 mm copper block weighing 400gm is machined so as to make its surfaces plane and corners to be sharp.

“Fig.2” Copper Plate (40 x 40 mm) with Thermocouple Connection

5.3 Schematic layout of setup

The final layout of setup on which experimentation is carried out is shown in fig. 3. The modified cold plate is placed on heater surface as shown in figure. The assembly is then insulated by using acrylic sheet. The thermocouples are connected to plate by drilling holes at required points and making the same holes in acrylic sheet. The control valves are provided for constant flow.

"Fig.3" Experimental Diagram of Setup

5.4 Setup preparation

1. Acrylic plate (150mm×150mm): It is used to hold the cold plate in its position from top surface. It is having a thermal conductivity of 0.2 $W.m^{-2}.K^{-1}$.
2. Bakelite plate (150mm×150mm): It gives the proper support heater from bottom surface. Its thermal conductivity is 0.2 $W.m^{-2}.K^{-1}$.
3. Mica (40mm×40mm):It acts as interface medium between heater and cold plate. It is having a thermal conductivity of 0.71 $W.m^{-2}.K^{-1}$.
4. Fiber glass wool: The fiber glass wool is very light-weight, flexible insulating material to reduce the heat loss from all the surfaces. It is formed from resin-bounded borosilicate glass fibers. It is water and fire resistant, it has low density and low toxicity. It's density in non-pressed state is 5-20 $kg.m^{-3}$. Thermal conductivity is 0.04 $W.m^{-2}.K^{-1}$. It occupies space between acrylic and Bakelite plate.

5.5 Experimental setup

1) It contains assembly of cold plate and heater with mica sheet as connecting medium.
a. K-type thermocouples are used having following specifications:
b. Sensitivity:41µV/ºC
c. Range:-200 ºC to 1350 ºC with good operating conditions in oxidizing atmosphere.
d. Dimmerstat with max load of 4 amp. And max kVA: 1.08
2) Water supplying tank with submersible pump motor (3Watt), its capacity 200L\H and control valve.
a. Water collector tank with measuring tank and control valve.
b. Glass wool as insulating material around the assembly parts.

Fig.3 shows the schematic diagram of the set-up used for the present experiment. The experiment is conducted with different power input and flow rates. The copper block is heated by nichrome foil heater of exact size attached underneath of the block. The heater is supported Bakelite plate gives the proper surface contact between heater and block it gives proper heat supplied through the block. The copper block is insulated glass-wool its size is 150x150x11$mm^3$to reduce the heat loss from all sides.

The heater is provides constant heat flux, the surface temperature is measured with two pre-calibrated K-type thermocouple it inserted to outer side of the copper block. Identical thermocouples are used away from the heater surface for ambient air temperature measurement. Power supplied to heater is measured the multi-meter and its controlled with dimmerstat. K-type thermocouple is connected to water inlet and water outlet of the cold plate. Water is supplied to the tank at small pump and flow rate is adjusted by the control valve, temperature of water both inlet and outlet are measured. Thus the reading is taken different flow rates for same power input and for different power input with same flow rates.

VI.RESULTS AND DISCUSSIONS

This chapter describes the experimental measurements for cold plate.

Calculation for heat transfer coefficient of water (h $Wm^{-2}K^{-1}$)

For heat transfer by water is

$Qw = mcp \Delta T$

$= mcp (Twout – Twin)$ ... (4)

Where,

Qw = Heat transfer by water

m = Mass flow rate

Cp = Specific heat of water

Δt = Temperature difference of water

For calculate h,

$Qw = hA \Delta T$

= hA (Twin + Twout \2) – Ts ... (5)

Where,

h = Heat transfer coefficient by water
A = Surface area of plate
Twin = Inlet temperature
Tout = Outlet temperature
Ts = Surface temperature

Also calculate the nussult number

Nu = hl \ k

Where,

h = Heat transfer coefficient by water
L = Total Length
K = Thermal conductivity

We can calculate the heat loss by cold plate

Qactual = Qw + Qloss ... (6)

Results obtained regarding selection of length of tubes are,

D = Diameter of the tube (m)
T_1= Temperature of heater plate (ºC)
T_2= Temperature of fluid at inlet (ºC)
T_f = Saturation temperature of fluid at given pressure (ºC)
L = Length of tube
R_{conv}= Resistance due to convection = $\frac{1}{h_w \times \pi \times D \times L}$

Experimentation is being carried out for two conditions:

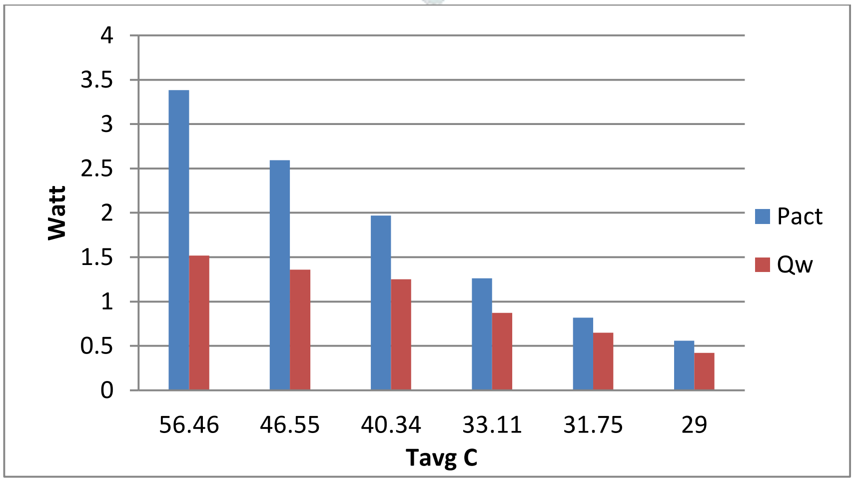
1. Keeping flow rate constant and varying power supplied
2. Keeping power constant and varying flow rate

Reynolds number is less than 2300 for all flow rates hence laminar flow conditions are selected. For first condition with mass flow rate ṁ = 0.00005 kg/s results are

1. Mass flow rate-0.00005 kg/s

6.1 Experimental Results for Mass Flow Rate of 0.00005 kg/s

Sr. No	P_{act} (W)	Tw_{in} (ºC)	Tw_{out} (ºC)	T_∞ (ºC)	Q_w (W)	T_{surf} (ºC)	h ($Wm^{-2}K^{-1}$)	Nu
1	3.38	22	29.26	22	1.5	35.17	114.65	178.4
2	2.59	22	28.49	22	1.3	33.63	134.88	209.9
3	1.96	22	27.98	22	1.2	31.31	165.95	256.7
4	1.26	22	26.18	22	0.8	27.98	187.23	291.4
5	0.81	22	25.11	22	0.6	26.09	213.25	331.9
6	0.55	22	24.02	22	0.4	25.05	172.38	268.3



"Fig.4" P_{act} Vs Q_w Graph for Average Surface Temperature at ṁ = 0.00005 kg/s

"Figure 4" shows heat removal by water at given flow rate considering from top surface and surrounding. For current flow rate heat removed by water varies from 68.79 % to 49.46 % of actual heat supplied from lower to higher power inputs. The mass flow rate is constant but the actual heat supplied is very less in that case the heat loss by the water is almost 5% to 10% its means heat removed by water is 90% to 95%.

After validating the experimental setup the top surface is now kept open to surrounding for natural convection. Heat transfer coefficient is calculated from experimental values and using law of conservation of energy:

$$P_{supp} - Q_{loss} = Q_w + h.A_s.(T_s - T_\infty) \quad .. \ (7)$$

For the equation we can calculate the Heat Transfer Coefficient

VII.CONCLUSION

The modification of the cold plate is reduce the heat loss and largely focused on high heat flux removal from computer chips and data centre unit in the recent year. When the mass flow rate minimum the heat transfer by water is almost 68.79% and mass flow rate is maximum the heat transfer by water is almost 85%

1) It is very useful in CPU, Data Centre Cooling and Spacecraft.
2) Heat transfer by water is more than air cooling system.
3) By lowering pressure at inlet below atmospheric water will evaporate at much lower temperature.
4) By making flow turbulent heat removing capacity will increase

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