Heat and Mass Transfer

MINI-PROJECT
Cooling Pad with “Air Bearing Heat Exchanger”

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1. **ABSTRACT:**

One of the biggest problems in IT industry is the “Thermal Brick Wall” problem (which limits PCs today to have a CPU clock speed of around 3GHz). The processing power keeps on growing and so does the heat generated by the processor. The modern day air-cooled heat exchangers are no longer just enough.

Several fold increase in heat exchanger size, along with higher volumetric flow rate, provides a solution to this problem but is not practical from real world point of view. Also, the tug of war between need of energy efficient devices and logistical considerations such as cost, equipment size and operating noise has resulted in a compromise that is far from ideal.

Here the “Air Bearing Heat Exchanger” proposed by Jeffery P. Koplow is used to design a cooling pad for laptop computers to provide a better heat exchanger which will enable high performance without overheating (to emphasise on the gravity of the problem: in July 2011 a boy died due to a fire started by his overheated laptop while he was asleep.)

The proposed heat exchanger provides several fold reduction in boundary layer thickness, pretty good immunity to heat-sink fouling due to particulate matter and other airborne contaminants and drastic reduction in noise. Thus this results in an energy efficient cooling pad that can be used anywhere without causing any disturbance and still be very efficient.
2. **INTRODUCTION:**

This project is aimed at providing a better cooling solution to the modern day laptops whose processing power has gone up but so has the heat generated by them.

A modern laptop comes with all the possible things that could be packed in the little volume to enhance its performance, which does not help the situation as there is not much progress in the development of heat exchangers.

*(Perhaps this example might emphasize on the gravity of the problem: in July 2011, a boy died due to a fire started by his overheated laptop while he was asleep.)*

This has resulted in a problem called the “thermal brick wall”—A situation where this imaginary wall prevents further growth in Personal computer speed.

Our target is the laptops, as they are increasingly more popular over their non-portable counterparts.

The problems with the use of this heat exchanger in laptop computers:

- The heat exchanger requires direct contact with the source.
- The size of the heat exchanger is not feasible as day by day laptops are decreasing in thickness. As a result there is no space for such a heat exchanger.
- Mass production of such heat exchanger is not likely, as companies manufacture PC’s for general public’s requirement, most of whom don’t need a high end laptop.
Hence, a cooling pad would be more desirable. Those who need high end laptops can use a cooling pad as per their requirement.

Cooling pad implies that there can be no direct contact of source with the heat exchanger.

Hence a system was developed to cool the hot air expelled by the heat exchanger.
3. LITERATURE REVIEW:

Moore’ law: The no. of transistors in a processor will double every 18 months i.e amount of data that can be processed is also doubled.

This law has been defied not because of lack of progress in field of computer hardware, but because of lack of comparable development in heat exchanger technology.

“Over last 40 years, CMOS, telecommunication, active sensing and imaging and other technologies have undergone tremendous technological innovation. Over the same historical period the technologies, design and performance of air-cooled heat exchangers has remained unchanged. The performance data for today’s state of the art heat exchangers and blowers is, in many cases, based on measurements performed in 1960s”. –DARPA

![Moore's Law Graph]

Figure 1

3.1 THE “THERMAL BRICK WALL”
In the recent years, the performance of air-cooled heat-exchangers has reached the limit of practicality for mass produced PCs. This has limited the CPU/GPU clock speed to \( \sim 3GHz \).

The situation is called “thermal brick wall”, where the heat generation limits further growth in CPU clock speed.

Any breakthrough in air-cooled heat exchanger technology would allow increase in this speed far beyond current limit.

![Figure 2](image)

As you can see Moore’s law is obeyed till Pentium 4, after which it does not quite follow the trend.
### 3.2 COMPARISION OF TEMPERATURE OF VARIOUS LAPTOP:

![CPU Temperature Graph](image)

<table>
<thead>
<tr>
<th>Product Description</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolimatech Megahaloma (Rev. A)</td>
<td>37</td>
</tr>
<tr>
<td>Prolimatech Megashadow</td>
<td>37</td>
</tr>
<tr>
<td>Zalman CNPS 10x Extreme</td>
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<tr>
<td>Prolimatech Megahaloma (Rev. B)</td>
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<tr>
<td>Corsair H70 2 Fans - High</td>
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</tr>
<tr>
<td>Zalman CNPS 10x Quilet (Fan High)</td>
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<tr>
<td>Corsair H70 2 Fans - Low</td>
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<td>Noctua NH-D14</td>
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<tr>
<td>Corsair H70 2 Fans - Auto</td>
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<tr>
<td>3R System Iceage Prima Boss II</td>
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</tr>
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<td>Coolage Cbr X120TF</td>
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<tr>
<td>EKL Alpenföhn Nordwand</td>
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<td>Geld Tronquol</td>
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<tr>
<td>Corsair H70 1 Fan - High</td>
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<tr>
<td>Noctua NH-U12P (2 Fans)</td>
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<td>Corsair A70 (2 Fans)</td>
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<td>Spiro Thernmax II</td>
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<td>Glacialtech F101</td>
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<td>Noctua NH-U9B (2 Fans)</td>
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<td>Zalman CNPS 9000 LED</td>
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<td>Noctua NH-U9B (1 Fan)</td>
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<td>Dynatron G950 Genius</td>
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<td>Nexus X1R 2300</td>
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<tr>
<td>Nexus X1R 3530</td>
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</tr>
</tbody>
</table>

Figure 3

### 3.3 THE CURRENT HEAT EXCHANGERS IN COMPUTERS

The current heat exchangers are not quite so efficient. The efficiency of small brushless motors is around 60%.
The formula for efficiency of a CPU fan would be:

\[ \varepsilon = \frac{p_{fan} \Phi_{fan}}{\varepsilon_{motor} V I}, \]

where

- \( p_{fan} \) = pressure drop
- \( \Phi_{fan} \) = volumetric flow rate
- \( V \) = voltage
- \( I \) = current

This gives the efficiency of the fan to be around 3%.

The efficiency of the heat exchange process is given by:

\[ \varepsilon_g = \frac{G}{G_{ideal}} = \frac{G}{C_p \rho \Phi} = \frac{1}{RC_p \rho \Phi} \]

This comes out to be around 0.1

Boundary layer problem: The stationary fins (which offer a very high surface area to volume

### 3.3.1 THE CONTEMPORARY HEAT SINK

The heat sink used these days is shown in the picture on the right.

The problems associated with this kind of heat exchanger are:

- Heat Sink fouling: The fan not only blows air through the plates, it also blows particulate matter and other airborne foreign matter, which settles in the heat sink. The dust settling on the heat exchanger surfaces acts as an insulating blanket that interferes with heat exchange and eventually chokes the airflow.
• Boundary layer problem: The stationary fins (which offer a very high surface area to volume ratio), cause a lot of stagnant or dead layer of air clinging to the surfaces. This does not really help.

• Poor efficiency: As shown in the earlier, the efficiency of the fan as well as the entire heat exchanger is pretty low.

• Noise: To increase the overall volumetric flow rate, the fan speed is increased (sometimes this is done as required in some laptops). This results in a higher level of noise.

So, either you can have an efficient heat exchanger (energy demon with lots of noise) or not-so-efficient resulting in a low performance computer

3.4 **DR. KOPLOW’S AIR BEARING HEAT EXCHANGER:**

The alternate heat exchanger invented by Dr. Koplow at Sandia National Labs solves all the four fundamental problems simultaneously (The boundary layer effect, heat sink fouling, the poor efficiency of small high speed turbo machine, and the noise. )
As in the case of conventional “fan-plus-heat-sink” CPU coolers, the heat source (the processor) is placed in thermal contact with the bottom surface, which acts as a heat spreader. This part is stationary. On the top of the spreader, a “heat-sink-impeller” is placed. This “heat-sink-impeller” is nothing but a spreader with fins on its top surface. It functions as a hybrid between a heat sink and an impeller. This part of the device is a rotating component. There is a gap of 0.03 mm air gap between the heat sink impeller and the stationary base plate. A high efficiency brushless motor is mounted directly on the base plate. This motor imparts rotation of the order of several thousand RPM to the impeller.

The air is sucked in through the gap between the heat sink impeller and the base plate and drawn into the central region without any fins. Then it is expelled through the dense array of fins.

Heat flows from the stationary aluminium base plate to the rotating heat sink impeller through the 0.03 mm thick circular disk of air. Now this interference of air does not in any way reduce the performance of the device as:

- The cross sectional area is large compared to the thickness hence low thermal resistance.
- The air that fills the gap is violently sheared between the rotating upper surface and the stationary lower surface. The convective mixing provided by this shearing effect provides a several fold increase in the thermal conductivity of the air in the gap region.
4. **PROPOSED SYSTEM**

Since the target here is a cooling pad, and the heat exchanger requires contact with the source, we propose a system where the motor runs in opposite direction and the main heat transfer takes place at the lower base plate instead of the fins.

Plus, we propose a network of coolant pipes running under the lower base plate, cooling the hot air expelled from laptop. This way the main objective of the “heat-sink-impeller” structure would be to suck the air and make sure that most of the heat is absorbed.

After the air is sucked and passed on to the air gap, the cold base plate with the coolant running under it, cools down the air in the gap. Now this process will take place effectively due to the effects described in the previous section.

The main contributor to the heat transfer in this situation would be convection.

Although laptop computer do get pretty hot, the temperature is very close to room temperature in most cases, hence radiation is neglected.

The design results in effective convective heat transfer, and thus helps in keeping the laptop at an acceptable temperature.

**4.1 FORMULAE:**

- $u = \frac{\pi DN}{60}$
  
  This will give the speed of the impellor and hence that of air wrt impellor

- $\dot{m} = uA$
  
  This will give the mass flow rate of the air
• \( Q = \dot{m}C_p \Delta T \) Heat at the upper base plate

• \( Q = kA \frac{dT}{dx} \) Heat from the lower base plate to the pipe

• \( Re = \frac{\rho v D}{\mu} \) Reynolds's number for the coolant flow

\[
Nu = \frac{(f/8)ReDPr}{1.07 + 12.7(f/8)^{0.5}[Pr^{0.67} - 1]} \left( \frac{\mu_m}{\mu_w} \right)^n
\]

Nusselt's number for the flow of the coolant assuming fully developed flow and constant wall temperature.

• \( Nu = \frac{hD}{k} \) To find out h

• \( Q_{net} = hA\Delta T \) To find the final heat transferred

4.2 \textbf{CALCULATIONS:}

\[
Q = hA\Delta T = 31.3 \times 4.93 \times 10^{-2} \times 20 = 30.236 \text{ J}
\]

\[
Q = kA \frac{\Delta T}{\Delta x}
\]

\[
\Rightarrow 30.236 = 173 \times 4.7310^{-2} \times \frac{(30 - T)}{0.5 \times 10^{-3}}
\]

\[
T = 29^\circ C
\]

For fully developed flow,
\[ Nu = \frac{(f/8)Re_dPr}{1.07 + 12.7 \left( \frac{f}{8} \right) [Pr^{0.67} - 1]} \times \left( \frac{\mu_m}{\mu_w} \right)^{0.11} \]

[ Relative roughness = 0.0015]

\[ \therefore Nu = \frac{(0.22/8)1.56 \times 10^5 \times 3.50}{1.07 + 12.7 \left( \frac{0.22}{8} \right) [3.5^{0.67} - 1]} \times 0.994 \]

\[ Nu = 10699.6 \]

\[ Nu = \frac{hl}{k} \]

\[ \therefore h = \frac{600.248 \times 10^{-6}}{l} \]

5. **RESULT:**

The heat transfer coefficient was found out in terms of the length of the coolant pipe (which of course will vary according to the size of the heat exchanger.) With this in hand, we can propose the size of the HE depending on the cooling required.

6. **CONCLUSION:**

Due to non-manufacturability of the system at our level, the results could not be verified. Although, theoretically this system should work just fine on a laptop considering further system is developed for supplying it power from the USB port and a design for the cooling pad itself.