PROJECT THESIS ON:

FABRICATION OF MICRO HEAT PIPES OF DIFFERENT DIAMETER FOR COOLING OF A DESKTOP COMPUTER PROCESSOR

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ABSTRACT

The experimental observations stated here is on the basis of heat transfer performance of parallel micro heat pipes (PMHPs) of different diameters (ID of 2mm & 3mm) taking Acetone as a working fluid that can be used for the cooling of desktop processor. The system incorporates of six single, equivalent distance & parallel copper micro heat pipes, without wick, slotted into two copper blocks at the evaporation section. Adiabatic section is bended at an angle of 90° and the condenser section is provided with ten parallel & equivalent distance copper sheets perpendicular to the PMHPs used as external fins. Heat transfer characteristics of PMHPs are determined by conducting the experiment using different diameters with Acetone as a working fluid. A GI sheet of 9X4 inch is heated up using an electric heater and the heat pipes are set up of that sheet. Temperature of the GI sheet and different parts of the heat pipes are taken at an interval of one minute and therefore analyzed the experimental data to evaluate the performance of the heat pipe. The experimental results are compared and it is found that the heat pipes of ID 2mm with the working fluid Acetone can reduce the temperature of the sheet better than the heat pipes of ID 3mm.

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CHAPTER 1

DESKTOP COMPUTER

1.1 INTRODUCTION

A computer is a general purpose device which can be programmed to carry out a finite set of arithmetic or logical operations. Since a sequence of operations can be readily changed, the computer can solve more than one kind of problem. Conventionally, a computer consists of at least one processing element and some form of memory. The processing element carries out arithmetic and logic operations, and a sequencing and control unit that can change the order of operations based on stored information. Peripheral devices allow information to be retrieved from an external source, and the result of operations saved and retrieved.

The first electronic digital computers were developed between 1940 and 1945 in the United Kingdom and United States. Originally they were the size of a large room, consuming as much power as several hundred modern personal computers (PCs).[1] In this era mechanical analog computers were used for military applications.

Modern computers based on integrated circuits are millions to billions of times more capable than the early machines, and occupy a fraction of the space.[2] Simple computers are small enough to fit into mobile devices, and mobile computers can be powered by small batteries. Personal computers in their various forms are icons of the Information Age and are what most people think of as "computers".

1.2 HISTORY OF COMPUTING

The first use of the word "computer" was recorded in 1613, referring to a person who carried out calculations, or computations, and the word continued with the same meaning until the middle of the 20th century. From the end of the 19th century the word began to take on its more familiar meaning, a machine that carries out computations.[3]

1.2.1 LIMITED-FUNCTION EARLY COMPUTERS

The history of the modern computer begins with two separate technologies, automated calculation and programmability, but no single device can be identified as the earliest computer, partly because of the inconsistent application of that term. A few devices are worth mentioning though, like some mechanical aids to computing, which were very successful and survived for centuries until the advent of the electronic calculator, like the Sumerian abacus, designed around 2500 BC[4] of which a descendant won a speed competition against a modern desk calculating machine in Japan in 1946,[5] the slide rules, invented in the 1620s, which were carried on five Apollo space missions, including to the moon[6] and arguably the astrolabe and the Antikythera mechanism, an ancient astronomical computer built by the Greeks around 80 BC.[7] The Greek mathematician Hero of Alexandria (c. 10–70 AD) built a mechanical theater which performed a play lasting 10 minutes and was operated by a complex system of ropes and drums that might be considered to be a means of deciding which parts of the mechanism performed which actions and when.[8] This is the essence of programmability.

Around the end of the 10th century, the French monk Gerbert d'Aurillac brought back from Spain the drawings of a machine invented by the Moors that answered either Yes or No to the questions it was asked.[9] Again in the 13th century, the monks Albertus Magnus and Roger Bacon built talking androids without any further development (Albertus Magnus complained that he had wasted forty years of his life when Thomas Aquinas, terrified by his machine, destroyed it).[10]

In 1642, the Renaissance saw the invention of the mechanical calculator,[11] a device that could perform all four arithmetic operations without relying on human intelligence.[12] The mechanical calculator was at the root of the development of computers in two separate ways. Initially, it was in trying to develop more powerful and more flexible calculators[13] that the computer was first theorized by Charles Babbage[14][15] and then developed.[16] Secondly, development of a low-cost electronic calculator, successor to the mechanical calculator, resulted in the development by Intel[17] of the first commercially available microprocessor integrated circuit.

1.2.2 FIRST GENERAL PURPOSE COMPUTERS

In 1801, Joseph Marie Jacquard made an improvement to the textile loom by introducing a series of punched paper cards as a template which allowed his loom to weave intricate patterns automatically. The resulting Jacquard loom was an important step in the development of computers because the use of punched cards to define woven patterns can be viewed as an early, albeit limited, form of programmability.

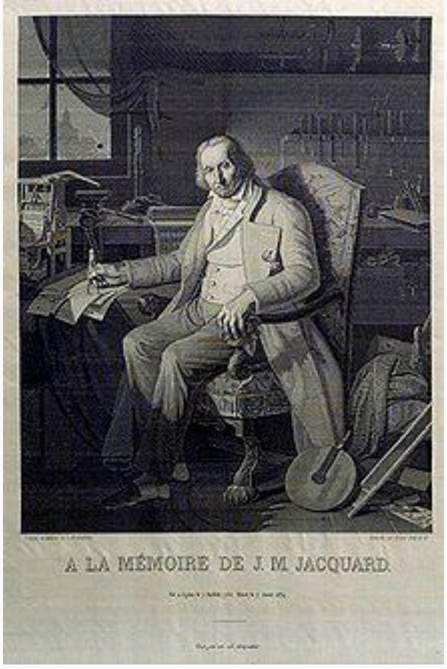


Fig 1.1: The Most Famous Image in the Early History of Computing [18]

This portrait of Jacquard was woven in silk on a Jacquard loom and required 24,000 punched cards to create (1839). It was only produced to order. Charles Babbage owned one of these portraits; it inspired him in using perforated cards in his analytical engine [19]

It was the fusion of automatic calculation with programmability that produced the first recognizable computers. In 1837, Charles Babbage was the first to conceptualize and design a fully programmable mechanical computer, his analytical engine.[20] Limited finances and Babbage's inability to resist tinkering with the design meant that the device was never completed—nevertheless his son, Henry Babbage, completed a simplified version of the analytical engine's computing unit (the mill) in 1888. He gave a successful demonstration of its use in computing tables in 1906. This machine was given to the Science museum in South Kensington in 1910.

In the late 1880s, Herman Hollerith invented the recording of data on a machine-readable medium. Earlier uses of machine-readable media had been for control, not data. "After some initial trials with paper tape, he settled on punched cards."[21] To process these punched cards he invented the tabulator, and the keypunch machines. These three inventions were the foundation of the modern information processing industry. Large-scale automated data processing of punched cards was performed for the 1890 United States Census by Hollerith's company, which later became the core of IBM. By the end of the 19th century a number of ideas and technologies, that would later prove useful in the realization of practical computers, had begun to appear: Boolean algebra, the vacuum tube (thermionic valve), punched cards and tape, and the teleprinter.

During the first half of the 20th century, many scientific computing needs were met by increasingly sophisticated analog computers, which used a direct mechanical or electrical model of the problem as a basis for computation. However, these were not programmable and generally lacked the versatility and accuracy of modern digital computers.

Alan Turing is widely regarded as the father of modern computer science. In 1936 Turing provided an influential formalization of the concept of the algorithm and computation with the Turing machine, providing a blueprint for the electronic digital computer.[22] Of his role in the creation of the modern computer, Time magazine in naming Turing one of the 100 most influential people of the 20th century, states: "The fact remains that everyone who taps at a keyboard, opening a spreadsheet or a word-processing program, is working on an incarnation of a Turing machine".[22]

The Atanasoff–Berry Computer (ABC) was the world's first electronic digital computer, albeit not programmable.[23] Atanasoff is considered to be one of the fathers of the computer.[24] Conceived in 1937 by Iowa State College physics professor John Atanasoff, and built with the assistance of graduate student Clifford Berry,[25] the machine was not programmable, being designed only to solve systems of linear equations. The computer did employ parallel computation. A 1973 court ruling in a patent dispute found that the patent for the 1946 ENIAC computer derived from the Atanasoff–Berry Computer.

The first program-controlled computer was invented by Konrad Zuse, who built the Z3, an electromechanical computing machine, in 1941.[26] The first programmable electronic computer was the Colossus, built in 1943 by Tommy Flowers.

George Stibitz is internationally recognized as a father of the modern digital computer. While working at Bell Labs in November 1937, Stibitz invented and built a relay-based calculator he dubbed the "Model K" (for "kitchen table", on which he had assembled it), which was the first to use binary circuits to perform an arithmetic operation. Later models added greater sophistication including complex arithmetic and programmability.[27]

A succession of steadily more powerful and flexible computing devices were constructed in the 1930s and 1940s, gradually adding the key features that are seen in modern computers. The use of digital electronics (largely invented by Claude Shannon in 1937) and more flexible programmability were vitally important steps, but defining one point along this road as "the first digital electronic computer" is difficult.

Shannon 1940 Notable achievements include:

- Konrad Zuse's electromechanical "Z machines". The Z3 (1941) was the first working machine featuring binary arithmetic, including floating point arithmetic and a measure of programmability. In 1998 the Z3 was proved to be Turing complete, therefore being the world's first operational computer.[28]

- The non-programmable Atanasoff–Berry Computer (commenced in 1937, completed in 1941) which used vacuum tube based computation, binary numbers, and regenerative capacitor memory. The use of regenerative memory allowed it to be much more compact than its peers (being approximately the size of a large desk or workbench), since intermediate results could be stored and then fed back into the same set of computation elements.

- The secret British Colossus computers (1943), [29] which had limited programmability but demonstrated that a device using thousands of tubes could be reasonably reliable and electronically reprogrammable. It was used for breaking German wartime codes.

- The Harvard Mark I (1944), a large-scale electromechanical computer with limited programmability.[30]

- The U.S. Army's Ballistic Research Laboratory ENIAC (1946), which used decimal arithmetic and is sometimes called the first general purpose electronic computer (since Konrad Zuse's Z3 of 1941 used electromagnets instead of electronics). Initially, however, ENIAC had an inflexible architecture which essentially required rewiring to change its programming.

1.2.3 STORED-PROGRAM ARCHITECTURE

Several developers of ENIAC, recognizing its flaws, came up with a far more flexible and elegant design, which came to be known as the "stored-program architecture" or von Neumann architecture. This design was first formally described by John von Neumann in the paper First Draft of a Report on the EDVAC, distributed in 1945. A number of projects to develop computers based on the stored-program architecture commenced around this time, the first of which was completed in 1948 at the University of Manchester in England, the Manchester Small-Scale Experimental Machine (SSEM). The Electronic Delay Storage Automatic Calculator (EDSAC), completed a year after the SSEM at Cambridge University, was the first practical, non-experimental implementation of the stored-program design and was put to use immediately for research work at the university. Shortly thereafter, the machine originally described by von Neumann's paper—EDVAC—was completed but did not see full-time use for an additional two years.

Nearly all modern computers implement some form of the stored-program architecture, making it the single trait by which the word "computer" is now defined. While the technologies used in computers have changed dramatically since the first electronic, general-purpose computers of the 1940s, most still use the von Neumann architecture.

Beginning in the 1950s, Soviet scientists Sergei Sobolev and Nikolay Brusentsov conducted research on ternary computers, devices that operated on a base three numbering system of −1, 0, and 1 rather than the conventional binary numbering system upon which most computers are based. They designed the Setun, a functional ternary computer, at Moscow State University. The device was put into limited production in the Soviet Union, but supplanted by the more common binary architecture.

1.2.4 SEMICONDUCTORS AND MICROPROCESSORS

Computers using vacuum tubes as their electronic elements were in use throughout the 1950s, but by the 1960s had been largely replaced by semiconductor transistor-based machines, which were smaller, faster, and cheaper to produce, required less power, and were more reliable. The first transistorized computer was demonstrated at the University of Manchester in 1953.[31] In the 1970s, integrated circuit technology and the subsequent creation of microprocessors, such as the Intel 4004, further decreased size and cost and further increased speed and reliability of computers. The 1980s witnessed home computers and the now ubiquitous personal computer.

1.2.5 THE BEGINNINGS OF THE PERSONAL COMPUTER INDUSTRY

IBM 610

The IBM 610 was designed between 1948 and 1957 by John Lentz at the Watson Lab at Columbia University as the Personal Automatic Computer (PAC) and announced by IBM as the 610 Auto-Point in 1957. The IBM 610 is according to Columbia University, the first personal computer because it was the first programmable computer intended for use by one person (e.g. in an office) and controlled from a keyboard. Although it was faulted for its speed, the IBM 610 handled floating-point arithmetic naturally. With a price tag of $55,000, only 180 units were produced.[32]

Simon

Simon was first mentioned in a 1949 book entitled, "Giant Brains, or Machines That Think" by American computer scientist Edmund Berkeley. This machine could demonstrate binary arithmetic on two-bit binary numbers. Berkeley went on to publish plans to build Simon in a series of Radio-Electronics issues in 1950 and 1951.[33] Although conceived by Berkeley, William A. Porter and two Columbia University graduate students of electrical engineering, Robert A. Jensen and Andrew Vall built the machine. Simon possessed many attributes of a personal computer, including the ability to perform addition, negation, greater than, and selection.[34] Moreover, it was considered at the time affordable, costing $600 in 1959.[35]

Olivetti Programma 101

The Programma 101 was Olivetti's first commercially produced "desktop computer"[36][37], presented at the 1965 New York World's Fair. Over 44,000 units were sold worldwide; in the US its cost at launch was $3,200. The Programma 101 had many of the features incorporated in modern personal computers, such as memory, keyboard, printing unit, magnetic card reader/recorder, control and arithmetic unit[38] and is considered by many as the first commercially produced desktop computer, showing the world that it was possible to create a desktop computer[39] (HP later copied the Programma 101 architecture for its HP9100 series).[40] [41].

Kenbak-1

The Kenbak-1 is considered by the Computer History Museum to be the world's first personal computer. It was designed and invented by John Blankenbaker of Kenbak Corporation in 1970, and was first sold in early 1971. Unlike a modern personal computer, the Kenbak-1 was built of small-scale integrated circuits, and did not use a microprocessor. The system first sold for US$750. Only around 40 machines were ever built and sold. In 1973, production of the Kenbak-1 stopped as Kenbak Corporation folded.

With only 256 bytes of memory, an 8-bit word size, and input and output restricted to lights and switches, the Kenbak-1 was most useful for learning the principles of programming but not capable of running application programs.

Data point 2200

A programmable terminal called the Data point 2200 is the earliest known device that bears some significant resemblance to the modern personal computer, with a screen, keyboard, and program storage.[42] It was made by CTC (now known as Data point) in 1970 and was a complete system in a small case bearing the approximate footprint of an IBM Selectric typewriter. The system's CPU was constructed from a variety of discrete components, although the company had commissioned Intel to develop a single-chip processing unit; there was a falling out between CTC and Intel, and the chip Intel had developed wasn't used. Intel soon released a modified version of that chip as the Intel 8008, the world's first 8-bit microprocessor.[43] The needs and requirements of the Data point 2200 therefore determined the nature of the 8008, upon which all successive processors used in IBM-compatible PCs were based. Additionally, the design of the Data point 2200's multi-chip CPU and the final design of the Intel 8008 were so similar that the two are largely software-compatible; therefore, the Data point 2200, from a practical perspective, can be regarded as if it were indeed powered by an 8008, which makes it a strong candidate for the title of "first microcomputer" as well.

Micral N

The French company R2E was formed by two former engineers of the Intertechnique company to sell their Intel 8008-based microcomputer design. The system was originally developed at the Institut National de la Recherche Agronomique to automate hygrometric measurements. The system ran at 500 kHz and included 16 kB of memory, and sold for 8500 Francs, about $1300US.

A bus, called Pluribus, was introduced that allowed connection of up to 14 boards. Boards for digital I/O, analog I/O, memory, floppy disk were available from R2E. The Micral operating system was initially called Sysmic, and was later renamed Prologue.

R2E was absorbed by Groupe Bull in 1978. Although Groupe Bull continued the production of Micral computers, it was not interested in the personal computer market, and Micral computers were mostly confined to highway toll gates (where they remained in service until 1992) and similar niche markets.

Xerox Alto and Star

The Xerox Alto, developed at Xerox PARC in 1973, was the first computer to use a mouse, the desktop metaphor, and a graphical user interface (GUI), concepts first introduced by Douglas Engelbart while at SRI International. It was the first example of what would today be recognized as a complete personal computer.

In 1981, Xerox Corporation introduced the Xerox Star workstation, officially known as the "8010 Star Information System". Drawing upon its predecessor, the Xerox Alto, it was the first commercial system to incorporate various technologies that today have become commonplace in personal computers, including a bit-mapped display, a windows-based graphical user interface, icons, folders, mouse, Ethernet networking, file servers, print servers and e-mail. It also included a programming language system called Smalltalk.

While its use was limited to the engineers at Xerox PARC, the Alto had features years ahead of its time. Both the Xerox Alto and the Xerox Star would inspire the Apple Lisa and the Apple Macintosh.

IBM 5100

IBM 5100 was a desktop computer introduced in September 1975, six years before the IBM PC. It was the evolution of a prototype called the SCAMP (Special Computer APL Machine Portable) that IBM demonstrated in 1973. In January 1978 IBM announced the IBM 5110, its larger cousin. The 5100 was withdrawn in March 1982.

When the PC was introduced in 1981, it was originally designated as the IBM 5150, putting it in the "5100" series, though its architecture wasn't directly descended from the IBM 5100.

Altair 8800

Development of the single-chip microprocessor was the gateway to the popularization of cheap, easy to use, and truly personal computers. It was only a matter of time before one such design was able to hit a sweet spot in terms of pricing and performance, and that machine is generally considered to be the Altair 8800, from MITS, a small company that produced electronics kits for hobbyists.

The Altair was introduced in a Popular Electronics magazine article in the January 1975 issue. In keeping with MITS's earlier projects, the Altair was sold in kit form, although a relatively complex one consisting of four circuit boards and many parts. Priced at only $400, the Altair tapped into pent-up demand and surprised its creators when it generated thousands of orders in the first month. Unable to keep up with demand, MITS eventually sold the design after about 10,000 kits had shipped.

The introduction of the Altair spawned an entire industry based on the basic layout and internal design. New companies like Cromemco started up to supply add-on kits, while Microsoft was founded to supply a BASIC interpreter for the systems. Soon after a number of complete "clone" designs, typified by the IMSAI 8080, appeared on the market. This led to a wide variety of systems based on the S-100 bus introduced with the Altair, machines of generally improved performance, quality and ease-of-use.

The Altair, and early clones, were relatively difficult to use. The machines contained no operating system in ROM, so starting it up required a machine language program to be entered by hand via front-panel switches, one location at a time. The program was typically a small driver for an attached paper tape reader, which would then be used to read in another "real" program. Later systems added bootstrapping code to improve this process, and the machines became almost universally associated with the CP/M operating system, loaded from floppy disk.

The Altair created a new industry of microcomputers and computer kits, with many others following, such as a wave of small business computers in the late 1970s based on the Intel 8080, Zilog Z80 and Intel 8085 microprocessor chips. Most ran the CP/M-80 operating system developed by Gary Kildall at Digital Research. CP/M-80 was the first popular microcomputer operating system to be used by many different hardware vendors, and many software packages were written for it, such as WordStar and dBase II.

Other machines of the era

Other 1977 machines that were important within the hobbyist community at the time included the Exidy Sorcerer, the NorthStar Horizion, and the Heathkit H8.

1977 and the emergence of the "Trinity"

By 1976 there were several firms racing to introduce the first truly successful commercial personal computers. Three machines, the Apple II, PET 2001 and TRS-80 were all released in 1977, eventually selling millions of machines. Byte magazine later referred to their launch as the "1977 Trinity".

PET

Chuck Peddle designed the Commodore PET (short for Personal Electronic Transactor) around his MOS 6502 processor. It was essentially a single-board computer with a new display chip (the MOS 6545) driving a small built-in monochrome monitor with 40×25 character graphics. The processor card, keyboard, monitor and cassette drive were all mounted in a single metal case. In 1982, Byte referred to the PET design as "the world's first personal computer".[44]

The PET shipped in two models; the 2001-4 with 4 kB of RAM, or the 2001-8 with 8 kB. The machine also included a built-in Datassette for data storage located on the front of the case, which left little room for the keyboard. The 2001 was announced in June 1977 and the first 100 units were shipped in mid October 1977.[45] However they remained back-ordered for months, and to ease deliveries they eventually canceled the 4 kB version early the next year.

Although the machine was fairly successful, there were frequent complaints about the tiny calculator-like keyboard, often referred to as a "Chiclet keyboard" due to the keys' resemblance to the popular gum candy. This was addressed in the upgraded "dash N" and "dash B" versions of the 2001, which put the cassette outside the case, and included a much larger keyboard with a full stroke non-click motion. Internally a newer and simpler motherboard was used, along with an upgrade in memory to 8, 16, or 32 KB, known as the 2001-N-8, 2001-N-16 or 2001-N-32, respectively.

The PET was the least successful of the 1977 Trinity machines, with fewer than 1 million sales.[46]

Apple II

Steve Wozniak (known as "Woz"), a regular visitor to Homebrew Computer Club meetings, designed the single-board Apple I computer and first demonstrated it there. With specifications in hand and an order for 100 machines at $500.00 US Dollars each from the Byte Shop, Woz and his friend Steve Jobs founded Apple Computer.

About 200 of the machines sold before the company announced the Apple II as a complete computer. It had color graphics, a full QWERTY keyboard, and internal slots for expansion, which were mounted in a high quality streamlined plastic case. The monitor and I/O devices were sold separately. The original Apple II operating system was only the built-in BASIC interpreter contained in ROM. Apple DOS was added to support the diskette drive; the last version was "Apple DOS 3.3".

Its higher price and lack of floating point BASIC, along with a lack of retail distribution sites, caused it to lag in sales behind the other Trinity machines until 1979, when it surpassed the PET. It was again pushed into 4th place when Atari introduced its popular Atari 8-bit systems.[47]

In spite of slow initial sales, the Apple II's lifetime was about eight years longer than other machines, and so accumulated the highest total sales. By 1985 2.1 million had sold and more than 4 million Apple IIs were shipped by the end of its production in 1993.[46]

TRS-80

Tandy Corporation introduced the TRS-80, retroactively known as the Model I as improved models were introduced. The Model I combined the motherboard and keyboard into one unit with a separate monitor and power supply. Although the PET and the Apple II offered certain features that were greatly advanced in comparison, Tandy's 3000+ RadioShack storefronts ensured that it would have widespread distribution that neither Apple nor Commodore could touch.

The Model I used a Zilog Z80 processor clocked at 1.77 MHz (the later models were shipped with a Z80A processor). The basic model originally shipped with 4 kB of RAM, and later 16 kB. Its other strong features were its full stroke QWERTY keyboard, small size, well written Floating BASIC and inclusion of a monitor and tape deck all for $599 US Dollars, a savings of $600 over the Apple II.

The Model I ran into some trouble meeting FCC regulations on radio interference due to its plastic case and exterior cables. Apple had resolved this issue with an interior metallic foil but this patch wouldn't work on the Model I.[48] Since the Model II and Model III were already in production Tandy decided to stop manufacturing the Model I. Radio Shack had sold 1.5 million Model I's by the cancellation in 1981.[46]

Home computers

Although the success of the Trinity machines was relatively limited in overall terms, as component prices continued to fall, many companies entered the computer business. This led to an explosion of low-cost machines known as home computers that sold millions of units before the market imploded in a price war in the early 1980s.

Atari 400/800

Atari was a well-known brand in the late 1970s, both due to their hit arcade games like Pong, as well as the hugely successful Atari VCS game console. Realizing that the VCS would have a limited lifetime in the market before a technically advanced competitor came along, Atari decided they would be that competitor, and started work on a new console design that was much more advanced.

While these designs were being developed, the Trinity machines hit the market with considerable fanfare. Atari's management decided to change their work to a home computer system instead. Their knowledge of the home market through the VCS resulted in machines that were almost indestructible and just as easy to use as a games machine – simply plug in a cartridge and go. The new machines were first introduced as the 400 and 800 in 1978, but production problems meant widespread sales did not start until the next year.

At the time, the machines offered what was then much higher performance than contemporary designs and a number of graphics and sound features that no other microcomputer could match. They became very popular as a result, quickly eclipsing the Trinity machines in sales. In spite of a promising start with about 600,000 sold by 1981, the looming price war left Atari in a bad position. They were unable to compete effectively with Commodore, and only about 2 million machines were produced by the end of their production run.[46]

TI-99

Texas Instruments (TI), at the time the world's largest chip manufacturer, decided to enter the home computer market with the Texas Instruments TI-99/4A. Announced long before its arrival, most industry observers expected the machine to wipe out all competition – on paper its performance was untouchable, and TI had enormous cash reserves and development capability.

When it was released in late 1979, TI took a somewhat slow approach to introducing it, initially focusing on schools. Contrary to earlier predictions, the TI-99's limitations meant it was not the giant-killer everyone expected, and a number of its design features were highly controversial. A total of 2.8 million units were shipped before the TI-99/4A was discontinued in March 1984.

VIC-20 and Commodore 64

Realizing that the PET could not easily compete with color machines like the Apple II and Atari, Commodore introduced the VIC-20 to address the home market. Limitations due to tiny 4 kB memory and its relatively limited display in comparison to those machines was offset by a low and ever falling price. Millions of VIC-20s were sold.

The best-selling personal computer of all time was released by Commodore International in 1982: the Commodore 64 (C64) sold over 17 million units before its end.[46] [49] The C64 name derived from its 64kb of RAM and it also came with a side mount ROM cartridge slot. It used the 6510 microprocessor CPU; MOS Technology, Inc. was then owned by Commodore.

BBC Micro

The BBC became interested in running a computer literacy series, and sent out a tender for a standardized small computer to be used with the show. After examining several entrants, they selected what was then known as the Acorn Proton and made a number of minor changes to produce the BBC Micro. The Micro was relatively expensive, which limited its commercial appeal, but with widespread marketing, BBC support and wide variety of programs, the system eventually sold as many as 1.5 million units. Acorn was rescued from obscurity, and went on to develop the ARM processor (Acorn RISC Machine) to power follow-on designs. The ARM is widely used to this day, powering a wide variety of products like the iPhone.

Price war and crash

TI had forced Commodore from the calculator market by dropping the price of their own-brand calculators to less than the cost of the chipsets they sold to 3rd parties to make the same design. Commodore's CEO, Jack Tramiel, vowed that this would not happen again, and purchased MOS Technology, Inc. to ensure a supply of chips. With his supply guaranteed, and good control over the component pricing, Tramiel deliberately launched a war against TI soon after the introduction of the Commodore 64.

The result was massive sales of the 64, albeit at almost no profit. And while Tramiel's target was TI, everyone in the home computer market was hurt by the process, many companies going bankrupt or exiting the business. In the end even Commodore's own finances were crippled by the demands of financing the massive building expansion needed to deliver the machines, and Tramiel was forced from the company.

Atari and Commodore were the only two major players left in the home computer market by 1984, and both were on shaky financial ground. Moreover, the systems' buyers found the actual usefulness of computers in homes to be somewhat limited. Aside from playing games, there were few uses that could support a market. Telecommunications was a popular hobby, but was still a highly technical endeavor in the pre-World Wide Web era. Business applications would run fine on these machines, but the possibility of selling a machine with the Atari name on it into businesses was close to zero.

Japanese computers

From the late 1970s to the early 1990s, Japan's personal computer market was largely dominated by domestic computer products. NEC's PC-88 and PC-98 was the market leader, though with some competition from the Sharp X1 and X68000, the FM-7 and FM Towns, and the MSX and MSX2, the latter also gaining some popularity in Europe. A key difference between Western and Japanese systems at the time was the latter's higher display resolutions (640x400) in order to accommodate Japanese text. Japanese computers also employed Yamaha FM synthesis sound boards since the early 1980s, allowing the production of higher quality chiptune music. Japanese computers were widely used to produce video games, though only a small portion of Japanese PC games were released outside of the country.[50] The most successful Japanese personal computer was NEC's PC-98, which sold more than 18 million units by 1999.[51]

The IBM PC

IBM responded to the success of the Apple II with the IBM PC, released in August, 1981. Like the Apple II and S-100 systems, it was based on an open, card-based architecture, which allowed third parties to develop for it. It used the Intel 8088 CPU running at 4.77 MHz, containing 29,000 transistors. The first model used an audio cassette for external storage, though there was an expensive floppy disk option. The cassette option was never popular and was removed in the PC XT of 1983.[52] The XT added a 10MB hard drive in place of one of the two floppy disks and increased the number of expansion slots from 5 to 8. While the original PC design could accommodate only up to 64k on the main board, the architecture was able to accommodate up to 640KB of RAM, with the rest on cards. Later revisions of the design increased the limit to 256K on the main board.

The IBM PC typically came with PC-DOS, an operating system based upon Gary Kildall's CP/M-80 operating system. In 1980, IBM approached Digital Research, Kildall's company, for a version of CP/M for its upcoming IBM PC. Kildall's wife and business partner, Dorothy McEwen, met with the IBM representatives who were unable to negotiate a standard non-disclosure agreement with her. IBM turned to Bill Gates, who was already providing the ROM BASIC interpreter for the PC. Gates offered to provide 86-DOS, developed by Tim Paterson of Seattle Computer Products. IBM rebranded it as PC-DOS, while Microsoft sold variations and upgrades as MS-DOS.

The impact of the Apple II and the IBM PC was fully demonstrated when Time named the home computer the "Machine of the Year", or Person of the Year for 1982 (January 3, 1983, "The Computer Moves In"). It was the first time in the history of the magazine that an inanimate object was given this award.

IBM PC clones

The original PC design was followed up in 1983 by the IBM XT, which was an incrementally improved design; it omitted support for the cassette, had more card slots, and was available with a 10MB hard drive. Although mandatory at first, the hard drive was later made an option and a two floppy disk XT was sold. While the architectural memory limit of 640K was the same, later versions were more readily expandable.

Although the PC and XT included a version of the BASIC language in read-only memory, most were purchased with disk drives and run with an operating system; three operating systems were initially announced with the PC. One was CP/M-86 from Digital Research, the second was PC-DOS from IBM, and the third was the UCSD p-System (from the University of California at San Diego). PC-DOS was the IBM branded version of an operating system from Microsoft, previously best known for supplying BASIC language systems to computer hardware companies. When sold by Microsoft, PC-DOS was called MS-DOS. The UCSD p-System OS was built around the Pascal programming language and was not marketed to the same niche as IBM's customers. Neither the p-System nor CPM-86 was a commercial success.

Because MS-DOS was available as a separate product, some companies attempted to make computers available which could run MS-DOS and programs. These early machines, including the ACT Apricot, the DEC rainbow 100, the Hewlett-Packard HP-150, the Seequa Chameleon and many others were not especially successful, as they required a customized version of MS-DOS, and could not run programs designed specifically for IBM's hardware. (See List of early non-IBM-PC-compatible PCs.) The first truly IBM PC compatible machines came from Compaq, although others soon followed.

Because the IBM PC was based on relatively standard integrated circuits, and the basic card-slot design was not patented, the key portion of that hardware was actually the BIOS software embedded in read-only memory. This critical element got reverse engineered, and that opened the floodgates to the market for IBM PC imitators, which were dubbed "PC clones". At the time that IBM had decided to enter the personal computer market in response to Apple's early success, IBM was the giant of the computer industry and was expected to crush Apple's market share. But because of these shortcuts that IBM took to enter the market quickly, they ended up releasing a product that was easily copied by other manufacturers using off the shelf, non-proprietary parts. So in the long run, IBM's biggest role in the evolution of the personal computer was to establish the de facto standard for hardware architecture amongst a wide range of manufacturers. IBM's pricing was undercut to the point where IBM was no longer the significant force in development, leaving only the PC standard they had established. Emerging as the dominant force from this battle amongst hardware manufacturers who were vying for market share was the software company Microsoft that provided the operating system and utilities to all PC's across the board, whether authentic IBM machines or the PC clones.

In 1984, IBM introduced the IBM Personal Computer/AT (more often called the PC/AT or AT) built around the Intel 80286 microprocessor. This chip was much faster, and could address up to 16MB of RAM but only in a mode that largely broke compatibility with the earlier 8086 and 8088. In particular, the MS-DOS operating system was not able to take advantage of this capability.

Apple Lisa and Macintosh

In 1983 Apple Computer introduced the first mass-marketed microcomputer with a graphical user interface, the Lisa. The Lisa ran on a Motorola 68000 microprocessor and came equipped with 1 megabyte of RAM, a 12-inch (300 mm) black-and-white monitor, dual 5¼-inch floppy disk drives and a 5 megabyte Profile hard drive. The Lisa's slow operating speed and high price (US$10,000), however, led to its commercial failure.

Drawing upon its experience with the Lisa, in 1984 Apple launched the Macintosh. Its debut was announced by a single broadcast during the 1984 Super Bowl XVIII of the now famous television commercial "1984" created by Ridley Scott and based on George Orwell's novel Nineteen Eighty-Four. The intention of the ad was to equate Big Brother with the IBM PC and a nameless female action hero (portrayed by Anya Major), with the Macintosh.

The Mac was the first successful mouse-driven computer with a graphical user interface or 'WIMP' (Windows, Icons, Menus, and Pointers). Based on the Motorola 68000 microprocessor, the Macintosh included many of the Lisa's features at a price of US$2,495. The Macintosh was initially introduced with 128 kb of RAM and later that year a 512 kb RAM model became available. To reduce costs compared the Lisa, the year-younger Macintosh had a simplified motherboard design, no internal hard drive, and a single 3.5" floppy drive. Applications that came with the Macintosh included MacPaint, a bit-mapped graphics program, and MacWrite, which demonstrated WYSIWYG word processing.

While not an immediate success upon its release, the Macintosh was a successful personal computer for years to come. This is particularly due to the introduction of desktop publishing in 1985 through Apple's partnership with Adobe. This partnership introduced the LaserWriter printer and Aldus PageMaker (now Adobe PageMaker) to users of the personal computer. After Steve Jobs was more or less forced to resign from Apple in 1985 and then started NeXT, a number of different models of Macintosh, including the Macintosh Plus and Macintosh II, were released to a great degree of success. The entire Macintosh line of computers was IBM's major competition up until the early 1990s.

GUIs spread

In the Commodore world, GEOS was available on the Commodore 64 and Commodore 128. Later, a version was available for PCs running DOS. It could be used with a mouse or a joystick as a pointing device, and came with a suite of GUI applications. Commodore's later product line, the Amiga platform, ran a GUI operating system by default. The Amiga laid the blueprint for future development of personal computers with its groundbreaking graphics and sound capabilities. Byte called it "the first multimedia computer... so far ahead of its time that almost nobody could fully articulate what it was all about."[53]

In 1985, the Atari ST, also based on the Motorola 68000 microprocessor, was introduced with the first color GUI in the Atari TOS. It could be modified to emulate the Macintosh using the third-party Spectre GCR device.

In 1987, Acorn launched the Archimedes range of high-performance home computers in Europe and Australasia. Based around their own 32-bit ARM RISC processor, the systems initially shipped with a GUI OS called Arthur. In 1989, Arthur was superseded by a multi-tasking GUI-based operating system called RISC OS. By default, the mice used on these computers had three buttons.

PC clones dominate

The transition from a PC-compatible market being driven by IBM to one driven primarily by a broader market began to become clear in 1986 and 1987; in 1986, the 32-bit Intel 80386 microprocessor was released, and the first '386-based PC-compatible was the Compaq Deskpro 386. IBM's response came nearly a year later with the initial release of the IBM Personal System/2 series of computers, which had a closed architecture and were a significant departure from the emerging "standard PC". These models were largely unsuccessful, and the PC Clone style machines outpaced sales of all other machines through the rest of this period.[54] Toward the end of the 1980s PC XT clones began to take over the home computer market segment from the specialty manufacturers such as Commodore International and Atari that had previously dominated. These systems typically sold for just under the "magic" $1000 price point (typically $999) and were sold via mail order rather than a traditional dealer network. This price was achieved by using the older 8/16 bit technology, such as the 8088 CPU, instead of the 32-bits of the latest Intel CPUs. These CPUs were usually made by a third party such as Cyrix or AMD. Dell started out as one of these manufacturers, under its original name PC Limited.

1990s and 2000s: NeXT

In 1990, the NeXTstation workstation computer went on sale, for "interpersonal" computing as Steve Jobs described it. The NeXTstation was meant to be a new computer for the 1990s, and was a cheaper version of the previous NeXT Computer. Despite its pioneering use of Object-oriented programming concepts, the NeXTstation was somewhat a commercial failure, and NeXT shut down hardware operations in 1993.

CD-ROM

The early 1990s saw the advent of the CD-ROM as an oncoming industry standard, and by the mid-90s one was built-in to almost all desktop computers, and towards the end of the 1990s, in laptops as well. Although introduced in 1982, the CD ROM was mostly used for audio during the 1980s, and then for computer data such as operating systems and applications into the 1990s. Another popular use of CD ROMs in the 1990s was multimedia, as many desktop computers started to come with built-in stereo speakers capable of playing CD quality music and sounds with the Sound Blaster sound card on PCs.

ThinkPad

IBM introduced its successful ThinkPad range at COMDEX 1992 using the series designators 300, 500 and 700 (allegedly analogous to the BMW car range and used to indicate market), the 300 series being the "budget", the 500 series "midrange" and the 700 series "high end". This designation continued until the late 1990s when IBM introduced the "T" series as 600/700 series replacements, and the 3,5 and 7 series model designations were phased out for A (3&7) & X (5) series. The A series was later partially replaced by the R series.

Zip drive

In 1994, the Zip drive was introduced by Iomega as a medium-capacity removable disk storage system. It aimed to replace the standard 3.5-inch (89 mm) floppy disk but failed to do so. Before the Zip was introduced, SyQuest was popular brand of removable media and drives, but these were expensive and largely unsuccessful due to reliability issues. Zip drives are still being sold as of 2008, however writable CDs are more common.

Dell

By the mid 1990s, Amiga, Commodore and Atari systems were no longer on the market, pushed out by strong IBM PC clone competition and low prices. Other previous competition such as Sinclair and Amstrad were no longer in the computer market. With less competition than ever before, Dell rose to high profits and success, introducing low-cost systems targeted at consumers and business markets using a direct-sales model. Dell surpassed Compaq as the world's largest computer manufacturer, and held that position until October 2006.

Power Macintosh, PowerPC

In 1994, Apple introduced the Power Macintosh series of high-end professional desktop computers for desktop publishing and graphic designers. These new computers made use of new Motorola PowerPC processors as part of the AIM alliance, to replace the previous Motorola 68k architecture used for the Macintosh line. During the '90s, the Macintosh remained with a low market share, but as the primary choice for creative professionals, particularly those in the graphics and publishing industries.

Risc PC

Also in 1994, Acorn Computers launched its Risc PC series of high-end desktop computers. The Risc PC (codenamed Medusa) was Acorn's next generation ARM-based RISC OS computer, which superseded the Acorn Archimedes.

BeBox

In 1995, Be Inc. released the BeBox computer, which used dual PowerPC 603 processors running at 66 MHz, and later 133 MHz with the Be operating system. The BeBox was largely a failure, with fewer than 2,000 units produced between October 1995 and January 1997, when production was ceased.

IBM clones, Apple back into profitability

Due to the sales growth of IBM clones in the '90s, they became the industry standard for business and home use. This growth was augmented by the introduction of Microsoft's Windows 3.0 operating environment in 1990, and followed by Windows 3.1 in 1992 and the Windows 95 operating system in 1995. The Macintosh was sent into a period of decline by these developments coupled with Apple's own inability to come up with a successor to the Macintosh operating system, and by 1996 Apple was almost bankrupt. In December 1996 Apple bought NeXT and in what has been described as a "reverse takeover", Steve Jobs returned to Apple in 1997. The NeXT purchase and Jobs' return brought Apple back to profitability, first with the release of Mac OS 8, a major new version of the operating system for Macintosh computers, and then with the PowerMac G3 and iMac computers for the professional and home markets. The iMac was notable for its transparent bondi blue casing in an ergonomic shape, as well as its discarding of legacy devices such as a floppy drive and serial ports in favor of Ethernet and USB connectivity. The iMac sold several million units and a subsequent model using a different form factor remains in production as of January 2012. In 2001 Mac OS X, the long awaited "next generation" Mac OS based on the NeXT technologies was finally introduced by Apple, cementing its comeback.

Writable CDs, MP3, P2P file sharing

The ROM in CD-ROM stands for Read Only Memory. In the late 1990s CD-R and later, rewritable CD-RW drives were included instead of standard CD ROM drives. This gave the personal computer user the capability to copy and "burn" standard Audio CDs which were playable in any CD player. As computer hardware grew more powerful and the MP3 format became pervasive, "ripping" CDs into small, compressed files on a computer's hard drive became popular. "Peer to peer" file sharing networks such as Napster, Kazaa and Gnutella arose to be used almost exclusively for sharing music files and became a primary computer activity for many individuals.

USB, DVD player

Since the late 1990s, many more personal computers started shipping that included USB (Universal Serial Bus) ports for easy plug and play connectivity to devices such as digital cameras, video cameras, personal digital assistants, printers, scanners, USB flash drives and other peripheral devices. By the early 21st century, all shipping computers for the consumer market included at least 2 USB ports. Also during the late 1990s DVD players started appearing on high-end, usually more expensive, desktop and laptop computers, and eventually on consumer computers into the first decade of the 21st century.

64 bits

In 2003, AMD shipped its 64-bit based microprocessor line for desktop computers, Opteron and Athlon 64. Also in 2003, IBM released the 64-bit based PowerPC 970 for Apple's high-end Power Mac G5 systems. Intel, in 2004, reacted to AMD's success with 64-bit based processors, releasing updated versions of their Xeon and Pentium 4 lines. 64-bit processors were first common in high end systems, servers and workstations, and then gradually replaced 32-bit processors in consumer desktop and laptop systems since about 2005.

INTEL Core i7-980X Processor Extreme Edition

Most recent processor boasting six cores each with a 3.33 GHz clock speed, turbo boost 3.6 GHz & LGA 1366 combined with a powerful graphics card (sold separately) this processor is set up to amaze. The Intel Core i7-980X Processor Extreme Edition is aimed at hardcore gamers or PC enthusiasts who heavily use 3D rendering, music and video reproduction applications and more. Code-named Gulftown, this processor benefits from extreme R&D from Intel, and boasts a Turbo Frequency of 3.6 GHz, and Hyper-Threading technology. The combination of 6 cores and Hyper-Threading gives a computer that is quick, extremely responsive, and ideal to work with several applications simultaneously. Other exciting details include SSE4.2 instruction set extensions, a 25.6GB/s memory bandwidth and a maximum TDP of 130W with all of this on a 32nm process technology.

Table 1.1: History of computing hardware

First Generation (Mechanical/ Electromechanical)	Calculators	Antikythera mechanism, Difference engine, Norden bombsight
	Programmable Devices	Jacquard loom, Analytical engine, Harvard Mark I, Z3
Second Generation (Vacuum Tubes)	Calculators	Atanasoff–Berry Computer, IBM 604, UNIVAC 60, UNIVAC 120
	Programmable Devices	Colossus, ENIAC, Manchester Small-Scale Experimental Machine, EDSAC, Manchester Mark 1, Ferranti Pegasus, Ferranti Mercury, CSIRAC, EDVAC, UNIVAC I, IBM 701, IBM 702, IBM 650, Z22
Third Generation (Discrete transistors and SSI, MSI, LSI Integrated circuits)	Mainframes	IBM 7090, IBM 7080, IBM System/360, BUNCH
	Minicomputer	PDP-8, PDP-11, IBM System/32, IBM System/36
Fourth Generation (VLSI integrated circuits)	Minicomputer	VAX, IBM System i
	4-bit microcomputer	Intel 4004, Intel 4040
	8-bit microcomputer	Intel 8008, Intel 8080, Motorola 6800, Motorola 6809, MOS Technology 6502,

		Zilog Z80
	16-bit microcomputer	Intel 8088, Zilog Z8000, WDC 65816/65802
	32-bit microcomputer	Intel 80386, Pentium, Motorola 68000, ARM architecture
	64-bit microcomputer[55]	Alpha, MIPS, PA-RISC, PowerPC, SPARC, x86-64
	Embedded computer	Intel 8048, Intel 8051
	Personal computer	Desktop computer, Home computer, Laptop computer, Personal digital assistant (PDA), Portable computer, Tablet PC, Wearable computer
Theoretical/ experimental	Quantum computer, Chemical computer, DNA computing, Optical computer, Spintronics based computer	

1.3 HARDWARE OF A MODERN PC

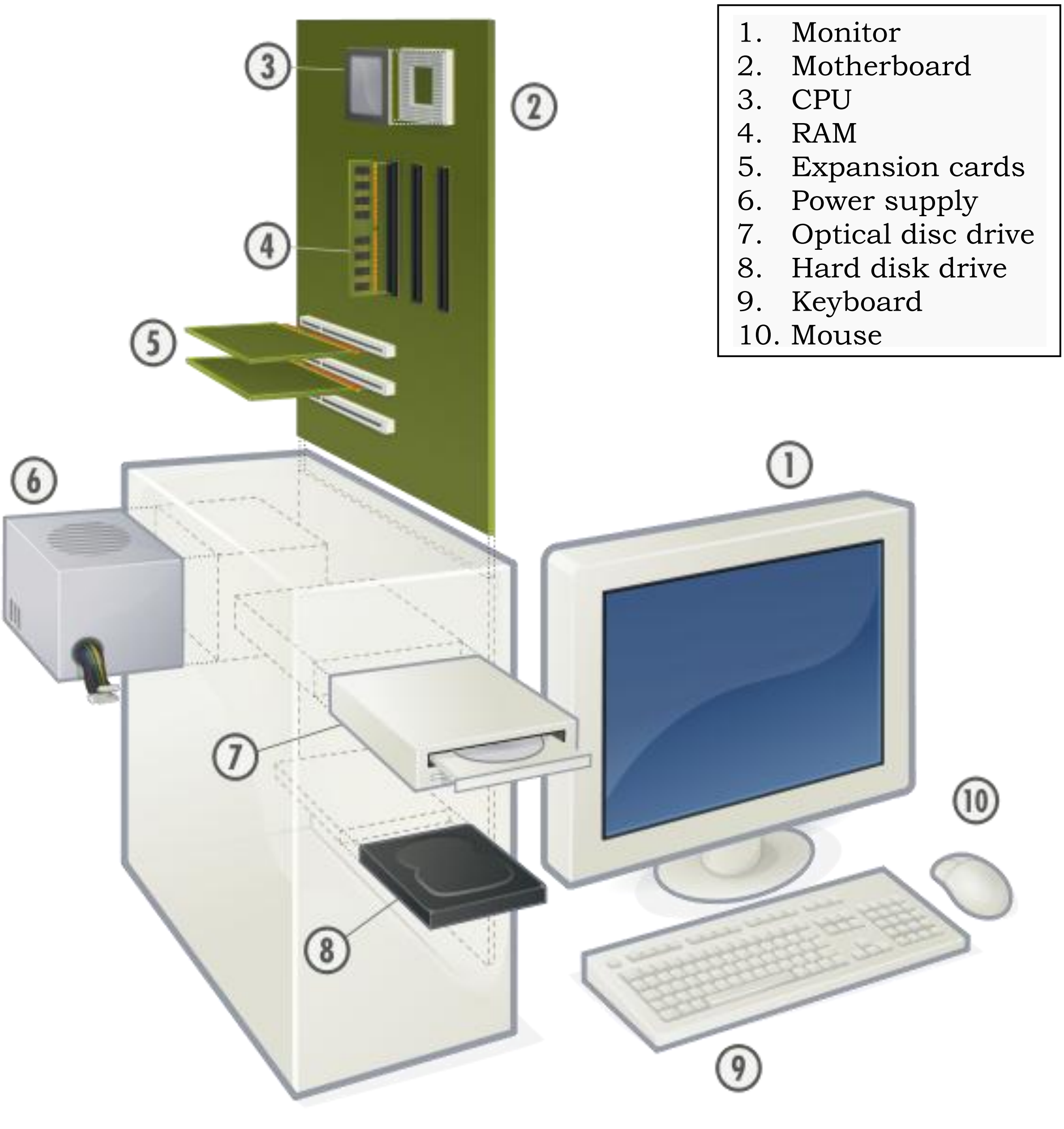


Fig 1.2: Hardware of a PC

1.3.1 MONITOR

A monitor is an electronic visual display for computers. The monitor comprises the display device, circuitry, and an enclosure. The display device in modern monitors is typically a thin film transistor liquid crystal display (TFT-LCD) thin panel, while older monitors use a cathode ray tube (CRT) about as deep as the screen size. Multiple technologies have been used for computer monitors. Until the 21st century most used cathode ray tubes but they have largely been superseded by LCD monitors.

1.3.2 MOTHERBOARD

A motherboard is a printed circuit board found in modern computers which holds many of the crucial components of the system, such as the central processing unit (CPU) and memory, and provides connectors for other peripherals. Motherboard specifically refers to a PCB with expansion capability.

1.3.3 CPU

The CPU (Central Processing Unit) performs most of the calculations which enable a computer to function, and is sometimes referred to as the "brain" of the computer. The more powerful the processor is, faster the PC will run. The speed of a processor – that is the number of instructions per second that it can carry out - is measured in gigahertz (GHz).

A multi-core processor effectively has more than one CPU on a single silicon chip, so it’s better able to handle multiple tasks at once. Most modern desktops have multi-core processors.

A home user after a mid-range PC might consider something like an i5 quadcore processor from chip-maker Intel. Keen gamers who want all the power they can get may be tempted by the latest high-power CPUs such as the i7, Intel’s top-of-the-range processor.

Most modern desktop processors will be 64-bit – this means that they can work with chunks of data made up of 64 binary digits. Older processors were 32-bit.

1.3.4 RAM

The Random-Access Memory (RAM) stores the code and data that are being actively accessed by the CPU & it is computer's short-term memory. Ram stores information & the amount determine the number of different tasks a PC carries out simultaneously. All modern desktop PCs will ship with at least 1GB of Ram, but aim for 2GB or more. Older versions of Windows weren't able to handle large amounts of Ram, but this is no longer a problem with the latest 64-bit version of Windows 7

1.3.5 EXPANSION CARDS

The expansion card in computing is a printed circuit board that can be inserted into an expansion slot of a computer motherboard or backplane to add functionality to a computer system via the expansion bus.

One edge of the expansion card holds the contacts (the edge connector) that fit exactly into the slot. They establish the electrical contact between the electronics (mostly integrated circuits) on the card and on the motherboard.

Connectors mounted on the bracket allow the connection of external devices to the card. Depending on the form factor of the motherboard and case, around one to seven expansion cards can be added to a computer system. 19 or more expansion cards can be installed in backplane systems. There are also other factors involved in expansion card capacity. For example, most graphics cards on the market as of 2010 are dual slot graphics cards, using the second slot as a place to put an active heat sink with a fan.

The primary purpose of an expansion card is to provide or expand on features not offered by the motherboard. For example, the original IBM PC did not provide graphics or hard drive capability. In that case, a graphics card and an ST-506 hard disk controller card provided graphics capability and hard drive interface respectively.

In the case of expansion of on-board capability, a motherboard may provide a single serial RS232 port or Ethernet port. An expansion card can be installed to offer multiple RS232 ports or multiple and higher bandwidth Ethernet ports. In this case, the motherboard provides basic functionality but the expansion card offers additional or enhanced ports.

1.3.6 POWER SUPPLY

A power supply unit (PSU) converts alternating current (AC) electric power to low-voltage DC power for the internal components of the computer. Some power supplies have a switch to change between 230 V and 115 V. Other models have automatic sensors that switch input voltage automatically, or are able to accept any voltage between those limits. Power supply units used in computers are nearly always switch mode power supplies (SMPS). The SMPS provides regulated direct current power at the several voltages required by the motherboard and accessories such as disk drives and cooling fans.

1.3.7 OPTICAL DISC DRIVE

Optical Disc Drives for reading from and writing to various kinds of optical media such as CD-ROMs, DVDs & Blu-ray Discs. Optical discs are the most common way of transferring digital video, and are popular for data storage as well.

1.3.8 HARD DISK DRIVES

Hard disk drive is a device for storing and retrieving digital information, primarily computer data. It consists of one or more rigid (hence "hard") rapidly rotating discs (often referred to as platters), coated with magnetic material and with magnetic heads arranged to write data to the surfaces and read it from them.

The computer’s hard disk drive provides long-term storage of data even if the PC is switched off. Until recently, hard drives were measured in gigabytes (GB), but now it’s not unusual to see terabyte (TB) hard drives (1TB is 1,024GB) when buying a new PC.

1.3.9 KEYBOARD & MOUSE

Keyboard is a device to input text and characters by depressing buttons (referred to as keys or buttons).

Mouse is a pointing device that detects two dimensional motion relative to its supporting surface.

CHAPTER 2

COMPUTER COOLING

2.1 INTRODUCTION

Just like all electronic components, CPU produces heat while it is running. Microprocessors heat up due to Joule effect, which is the process of transforming electrical energy into heat. Inside the CPU there are several wires (conductors) in charge of its internal interconnections. The Joule effect appears due to the shock between electrons and the conductor ion mesh, leading to an increase in the temperature of the conductor.

Integrated circuits are the prime generators of heat in modern computers, but ultimately acceptable performance can often only be achieved by accepting significant heat generation.

In operation, the temperature of a computer's components will rise until the heat transferred to the surroundings is equal to the heat produced by the component, i.e., thermal equilibrium is reached. For reliable operation, the temperature must never exceed a specified maximum permissible value for each component. For semiconductors, instantaneous junction temperature, rather than component case, heat sink, or ambient temperature is critical.

The heat generated by an electronic device needs to be removed as soon as possible; otherwise its internal temperature will increase. If the device gets too hot internally, its internal circuits can be damaged.

When the CPU works above the maximum admissible temperature set by its manufacturer, the following problems can occur:

- Reduction of CPU life-span
- Random freezes
- Random resets
- Eventually the CPU can get burned.

Computer cooling is required to remove the waste heat produced by computer components by heat transfer, to keep components within permissible operating temperature limits.

Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy and heat between physical systems. Heat transfer is classified into various mechanisms, such as heat conduction, convection, thermal radiation, and transfer of energy by phase changes.

Components that are susceptible to temporary malfunction or permanent failure if overheated include integrated circuits such as CPUs, chipset, graphics cards, and hard disk drives.

Cooling can be hindered by:

- Dust acting as a thermal insulator and impeding airflow, thereby reducing heat sink and fan performance.

- Poor airflow including turbulence due to friction against impeding components such as ribbon cables, or improper orientation of fans, can reduce the amount of air flowing through a case and even create localized whirlpools of hot air in the case. In some cases of equipment with bad thermal design, cooling air can easily flow out through "cooling" holes before passing over hot components; cooling in such cases can often be improved by blocking of selected holes.

- Poor heat transfer due to poor thermal contact between components to be cooled and cooling devices. This can be improved by the use of thermal compounds to even out surface imperfections, or even by lapping.

2.2 COOLING SYSTEM

2.2.1 AIR COOLING

Fans are most commonly used for air cooling when natural convection is insufficient. Computer fans may be fitted to the computer case, and attached to CPUs, GPUs, chipset, PSU, drives and PCI cards. Desktop computers typically use one or more fans for cooling. Almost all desktop power supplies have at least one fan to exhaust air from the case. Most manufacturers recommend bringing cool, fresh air in at the bottom front of the case, and exhausting warm air from the top rear.

2.2.2 LIQUID COOLING

Liquid cooling systems for PCs work almost the same way as car radiators do. Water is circulated through a block that sits on top of the processor and pumped to a radiator where the heat is conducted into the fins and then into the air. Water cooling is very effective, water has a reasonable thermal conductivity, compared to air anyway, which means heat is sucked away from the processor quickly, water's massive specific heat capacity means it makes an excellent heat sink in itself. As liquid nitrogen boils at -196 °C, far below the freezing point of water, it is valuable as an extreme coolant for short over clocking sessions. Liquid helium, colder than liquid nitrogen, has also been used for cooling.

2.2.3 THERMO-ELECTRIC COOLERS

Thermo-electric coolers use the Peltier effect to transfer heat from one side of a material to the other. It consists of a sandwich made from two dissimilar semiconductors across which a current is applied. This causes heat to be transferred from one side to the other. Change the polarity of the current and it reverses the flow.

2.2.4 SOFT COOLING

Soft cooling is done using halt instructions to turn off or put in standby state CPU subparts that aren't being used or by underclocking the CPU

2.2.5 HEAT SINK

In electronic systems, a heat sink is a passive component that cools a device by dissipating heat into the surrounding air. Heat sinks are used to cool electronic components such as high-power semiconductor devices, optoelectronic devices, higher-power lasers and LEDs. A heat sink is designed to increase the surface area in contact with the cooling medium surrounding it, such as the air. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the factors which affect the thermal performance of a heat sink. Heat sinks are used to cool computer central processing units or graphics processors. Heat sink attachment methods and thermal interface materials also affect the eventual die temperature of the integrated circuit. Thermal adhesive or thermal grease fills the air gap between the heat sink and device to improve its thermal performance. Theoretical, experimental and numerical methods can be used to determine a heat sink's thermal performance.

Microprocessor cooling by heat sink

Heat dissipation is an unavoidable by-product of all but micro power electronic devices and circuits.[63] In general, the temperature of the device or component will depend on the thermal resistance from the component to the environment, and the heat dissipated by the component. To ensure that the component temperature does not overheat, a thermal engineer seeks to find an efficient heat transfer path from the device to the environment. The heat transfer path may be from the component to a printed circuit board (PCB), to a heat sink, to air flow provided by a fan, but in all instances, eventually to the environment.

Two additional design factors also influence the thermal/mechanical performance of the thermal design:

1. The method by which the heat sink is mounted on a component or processor. This will be discussed under the section attachment methods.
2. For each interface between two objects in contact with each other, there will be a temperature drop across the interface. For such composite systems, the temperature drop across the interface may be appreciable.[64] This temperature change may be attributed to what is known as the thermal contact resistance.[64] Thermal interface materials (TIM) decrease the thermal contact resistance.

Basic heat sink heat transfer principle

A heat sink is an object that transfers thermal energy from a higher temperature to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water or in the case of heat exchangers, refrigerants and oil. If the fluid medium is water, the 'heat sink' is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction.

To understand the principle of a heat sink, consider Fourier's law of heat conduction. Joseph Fourier was a French mathematician who made important contributions to the analytical treatment of heat conduction.[56] Fourier's law of heat conduction, simplified to a one-dimensional form in the x-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region. The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred.

$$q_k = -kA\frac{dT}{dx} \qquad (\text{eq}^{n}\ 2.1)$$

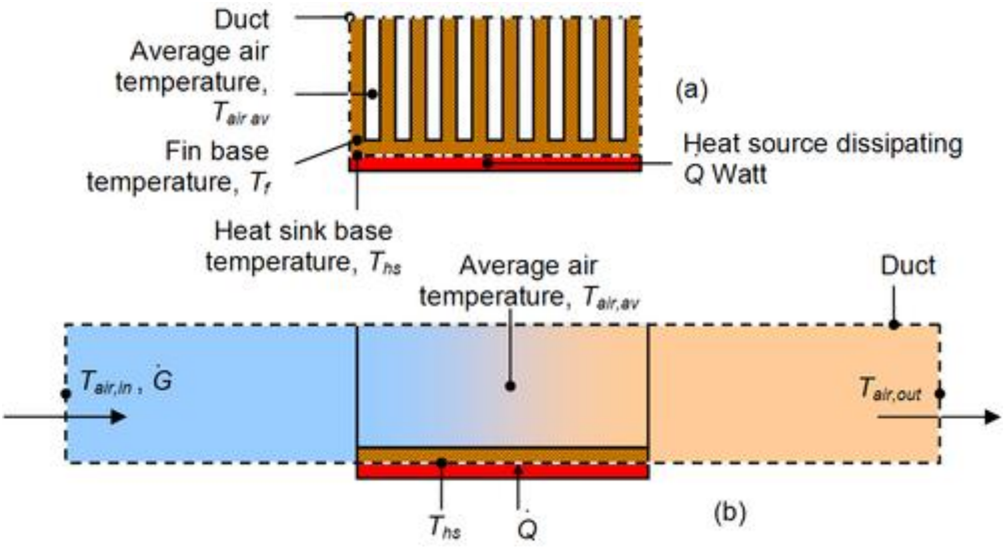


Fig 2.1: Sketch of a heat sink in a duct

Consider a heat sink in a duct, where air flows through the duct, as shown in Figure 2.1 It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes shown in Figure 2.1 gives the following set of equations.

$$\dot{Q} = \dot{m}c_{p,in}(T_{air,out} - T_{air,in}) \qquad \text{(eq}^{\text{n}}\text{ 2.2)}$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \qquad \text{(eq}^{\text{n}}\text{ 2.3)}$$

where

$$T_{air,av} = \frac{T_{air,in} + T_{air,out}}{2} \qquad \text{(eq}^{\text{n}}\text{ 2.4)}$$

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used.

The above equations show that

- When the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat sink base temperature.
- The inlet air temperature relates strongly with the heat sink base temperature. For example, if there is recirculation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat sink base temperature.
- If there is no air flow around the heat sink, energy cannot be transferred.
- A heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe".[57]

Natural convection requires free flow of air over the heat sink. If fins are not aligned vertically, or if pins are too close together to allow sufficient air flow between them, the efficiency of the heat sink will decline.

Design factors which influence the thermal performance of a heat sink

a) Thermal resistance

For semiconductor devices used in a variety of consumer and industrial electronics, the idea of thermal resistance simplifies the selection of heat sinks. The heat flow between the semiconductor die and ambient air is modeled as a series of resistances to heat flow; there is a resistance from the die to the device case, from the case to the heat sink, and from the heat sink to the ambient. The sum of these resistances is the total thermal resistance from the die to the ambient. Thermal resistance is defined as temperature rise per unit of power, analogous to electrical resistance, and is expressed in units of degrees Celsius per watt (°C/W). If the device dissipation in watts is known, and the total thermal resistance is calculated, the temperature rise of the die over ambient can be calculated.

The idea of thermal resistance of a semiconductor heat sink is an approximation. It does not take into account non-uniform distribution of heat over a device or heat sink. It only models a system in thermal equilibrium, and does not take into account the change in temperatures with time. Nor does it reflect the non-linearity of radiation and convection with respect to temperature rise. However, manufacturers tabulate typical values of thermal resistance for heat sinks and semiconductor devices, which allows selection of commercially manufactured heat sinks to be simplified. [58]

Commercial extruded aluminum heat sinks have a thermal resistance (heat sink to ambient air) ranging from 0.4 °C/W for a large sink meant for TO3 devices, up to as high as 85 °C/W for a clip-on heat sink for a TO92 small plastic case.[58] The famous, popular, historic and notable 2N3055 power transistor in a TO3 case has an internal thermal resistance from junction to case of 1.52 °C/W.[59] The contact between the device case and heat sink may have a thermal resistance of between 0.5 up to 1.7 °C/W, depending on the case size, and use of grease or insulating mica washer.[58]

b) Material

The most common heat sink materials are aluminum alloys.[60] Aluminum alloy 1050A has one of the higher thermal conductivity values at 229 W/m•K [66] but is mechanically soft. Aluminum alloys 6061 and 6063 are commonly used, with thermal conductivity values of 166 and 201 W/m•K, respectively. The values depend on the temper of the alloy.

Copper has around twice the conductivity of aluminum and faster thermal absorption, but is three times as dense [60] and, depending on the market, around four to six times more expensive than aluminum. [60] Aluminum can be extruded, but copper cannot. Copper heat sinks are machined and skived. Another method of manufacture is to solder the fins into the heat sink base.

Diamond is another heat sink material, and its thermal conductivity of 2000 W/m•K exceeds copper five-fold. [62] In contrast to metals, where heat is conducted by delocalized electrons, lattice vibrations are responsible for diamond's very high thermal conductivity. For thermal management applications, the outstanding thermal conductivity and diffusivity of diamond is an essential. Nowadays synthetic diamond is used as sub mounts for high-power integrated circuits and laser diodes.

Composite materials can be used. Examples are a copper-tungsten pseudo alloy, AlSiC (silicon carbide in aluminum matrix), Dymalloy (diamond in copper-silver alloy matrix), and E-Material (beryllium oxide in beryllium matrix). Such materials are often used as substrates for chips, as their thermal expansion coefficient can be matched to ceramics and semiconductors.

c) Fin efficiency

Fin efficiency is one of the parameters which makes a higher thermal conductivity material important. A fin of a heat sink may be considered to be a flat plate with heat flowing in one end and being dissipated into the surrounding fluid as it travels to the other.[63] As heat flows through the fin, the combination of the thermal resistance of the heat sink impeding the flow and the heat lost due to convection, the temperature of the fin and, therefore, the heat transfer to the fluid, will decrease from the base to the end of the fin. Fin efficiency is defined as the actual heat transferred by the fin, divided by the heat transfer were the fin to be isothermal (hypothetically the fin having infinite thermal conductivity). Equations 5 and 6 are applicable for straight fins.

$$\eta_f = \frac{\tanh(mL_c)}{mL_c}$$ [64] (eq^n 2.5)

$$mL_c = \sqrt{\frac{2h_f}{kt_f}}L_f$$ [64] (eq^n 2.6)

Where:

- h_f is the convection coefficient of the fin
  - ✓ Air: 10 to 100 W/(m^{2}K)
  - ✓ Water: 500 to 10,000 W/(m^{2}K)
- k is the thermal conductivity of the fin material
  - ✓ Aluminum: 120 to 240 W/(m·K)
- L_f is the fin height (m)
- t_f is the fin thickness (m)

Fin efficiency is increased by decreasing the fin aspect ratio (making them thicker or shorter), or by using more conductive material (copper instead of aluminum, for example).

d) Spreading resistance

Another parameter that concerns the thermal conductivity of the heat sink material is spreading resistance. Spreading resistance occurs when thermal energy is transferred from a small area to a larger area in a substance with finite thermal conductivity. In a heat sink, this means that heat does not distribute uniformly through the heat sink base. The spreading resistance phenomenon is shown by how the heat travels from the heat source location and causes a large temperature gradient between the heat source and the edges of the heat sink. This means that some fins are at a lower temperature than if the heat source were uniform across the base of the heat sink. This non uniformity increases the heat sink's effective thermal resistance.

To decrease the spreading resistance in the base of a heat sink:

- Increase the base thickness
- Choose a different material with better thermal conductivity
- Use a vapor chamber or heat pipe in the heat sink base.

e) Fin arrangements

Fig 2.2: A pin, straight and flared fin heat sink types

A pin fin heat sink is a heat sink that has pins that extend from its base. The pins can be cylindrical, elliptical or square. A pin is by far one of the more common heat sink types available on the market. A second type of heat sink fin arrangement is the straight fin. These run the entire length of the heat sink. A variation on the straight fin heat sink is a cross cut heat sink. A straight fin heat sink is cut at regular intervals.

In general, the more surface area a heat sink has, the better it works.[57] However, this is not always true. The concept of a pin fin heat sink is to try to pack as much surface area into a given volume as possible.[57] As well, it works well in any orientation. Kordyban[57] has compared the performance of a pin fin and a straight fin heat sink of similar dimensions. Although the pin fin has 194 cm^2 surface area while the straight fin has 58 cm^2, the temperature difference between the heat sink base and the ambient air for the pin fin is 50 °C. For the straight fin it was 44 °C or 6 °C better than the pin fin. Pin fin heat sink performance is significantly better than straight fins when used in their intended application where the fluid flows axially along the pins rather than only tangentially across the pins.

Another configuration is the flared fin heat sink; its fins are not parallel to each other, as shown in figure 4. Flaring the fins decreases flow resistance and makes more air go through the heat sink fin channel; otherwise, more air would bypass the fins. Slanting them keeps the overall dimensions the same, but offers longer fins. Forghan, et al.[65] have published data on tests conducted on pin fin, straight fin and flared fin heat sinks. They found that for low approach air velocity, typically around 1 m/s, the thermal performance is at least 20% better than straight fin heat sinks. Lasance and Eggink[66] also found that for the bypass configurations that they tested, the flared heat sink performed better than the other heat sinks tested.

Table 2.1: Comparison of a pin fin and straight fin heat sink [57]

Heat sink fin type	Width [cm]	Length [cm]	Height [cm]	Surface area [cm^2]	Volume [cm^3]	Temperature difference, $T_{case}-T_{air}$ [°C]
Straight	2.5	2.5	3.2	58	20	44
Pin	3.8	3.8	1.7	194	24	51

f) Surface color

Heat transfer by radiation is a function of both the heat sink temperature, and the temperature of the surroundings that the heat sink is optically coupled with. When both of these temperatures are on the order of 0 °C to 100 °C, the contribution of radiation compared to convection is generally small, and this factor is often neglected. In this case, finned heat sinks operating in either natural-convection or forced-flow will not be affected significantly by surface emissivity.

In situations where convection is low, such as a flat non-finned panel with low airflow, radioactive cooling can be a significant factor. Here the surface properties may be an important design factor. Matte-black surfaces will radiate much more efficiently than shiny bare metal in the visible spectrum.[67] A shiny metal surface has low effective emissivity due to its low surface area. While the emissivity of a material is tremendously energy (frequency) dependent, the noble metals demonstrate very low emissivity in the Near-Infrared spectrum. The emissivity in the visible spectrum is closely related to color. For most materials, the emissivity in the visible spectrum is similar to the emissivity in the infrared spectrum; however there are exceptions, notably certain metal oxides that are used as "selective surfaces".

In a vacuum or in outer space, there is no convective heat transfer, thus in these environments, radiation is the only factor governing heat flow between the heat sink and the environment. For a satellite in space, a 100 °C (373 Kelvin) surface facing the sun will absorb a lot of radiant heat, since the sun's surface temperature is nearly 6000 Kelvin, whereas the same surface facing deep-space will radiate a lot of heat, since deep-space has an effective temperature of only a few Kelvin.

2.2.6 HEAT PIPES

The increasing heat generation of the microprocessor with increasing working speed and also the space constraint made the thermal management of desktop computers challenging. Conventional fan cooling in electronic devices with the huge noise generation and power consumption with moving parts are becoming unreliable. The CPU of a desktop and server computer releases 80 to 130 W and notebook computer 25 to 50W of heat energy [68]. It became more challenging because the chip surface temperature should not be allowed to go beyond 100°C [69]. In the latter case, the heating area of the chipset has become as small as 1– 4 cm. It is expected that conventional cooling fan system will not be able to meet the futuristic thermal needs of the next generation computers.

Scientists started to apply liquid submersion cooling, active and passive heat sink cooling, thermoelectric cooling etc. in computer cooling. But soon these became more or less obsolete for integration and reliability issues. Even the most recent technique of integrated chip cooling is not acclaimed by all because of the huge cost.

With the development in the two-phase heat transfer systems and porous media technology, a heat pipe heat sink has come up as one of the most potential candidate to meet these challenging needs which is a passive cooling device & emerging as a cost-effective thermal design solution that requires no moving parts, and operates silently, more reliably.

A simple but effective way to transfer large amounts of heat is to use a heat pipe. When a material changes state from gas to liquid, liquid to solid or such like, large amounts of heat are either absorbed or emitted.

Heat pipe as cooler

The heat pipes in PC coolers are sealed pipes with a small amount of liquid, usually distilled water; this is under low pressure to bring down the boiling point. The inside of the pipe is lined with a layer that acts as a wick, a woven wire mesh or sintered copper (copper foam is promised soon).

The water is boiled at the source of the heat, the gas diffuses to the cooler ends of the pipes where it condenses into the wick and capillary action takes it back to the site of the heat again. Only a tiny amount of liquid is moving, but the relatively large amount of energy required for the change of state means its shifting lots of joules. All with no maintenance or power required.

The vapor chamber is a variation on the heat pipe, and has been around a while but not been taken up much. Here instead of a set of pipes passing though the heat spreader, the whole heat pipe is flattened out and shaped to fit over the processor, with the rest of the heat sink built on top.

Currently, one of the highest volume applications for heat pipes is cooling the Pentium processors in notebook computers. Due to the limited space and power available in notebook computers, heat pipes are ideally suited for cooling the high power chips.

Fan assisted heat sinks require electrical power and reduce battery life. Standard metallic heat sinks capable of dissipating the heat load are too large to be incorporated into the notebook package. Heat pipes, on the other hand, offer a high efficiency, passive, compact heat transfer solution. Three or four millimeter diameter heat pipes can effectively remove the high flux heat from the processor. The heat pipe spreads the heat load over a relatively large area heat sink, where the heat flux is so low that it can be effectively dissipated through the notebook case to ambient air. The heat sink can be the existing components of the notebook, from Electro-Magnetic Interference (EMI) shielding under the key pad to metal structural components.

Fig 2.3: Use of heat pipe in laptop

Fig 2.4: Use of heat pipe in notebook

Fig 2.5: Use of heat pipe in graphics card

History of heat pipes

The very first advent of heat pipe was in 1944 by R.S.Gauglar [70] of General Motors, which was rediscovered by George Grover and his co-workers [71] of the Los Alamos Scientific Laboratory in 1963. Since then continuous research and development have gone behind heat pipe.

Starting in the 1980s Sony began incorporating heat pipes into the cooling schemes for tuners & amplifiers in electronic products in place of both forced convection and passive finned heat sinks. Cao, Y. and Gao, M. [72] designed, fabricated, and tested wickless, cross-grooved thermal spreaders, which were made of Copper or Aluminum. The maximum heat flux achieved was about 40 W/cm2 for methanol and 110W/cm2 for water with a total heat input of 393W.

In the development process, as the electronic devices became more mobile in use and tiny in size, scientists started to concentrate more on micro and miniature heat pipes. Zhang, J. and Wong, H. [73] studied heat transfer and fluid flow in an idealized micro heat pipe with the support of NASA and LaSPACE. They made an analysis for four different values of length to width ratio of an idealized micro heat pipe, viz. 20, 50, 100, and 200. In a study of micro and miniature heat pipes, developed by A.R. Anand [74], attempts have been made to develop a one dimensional numerical model of micro heat pipes, taking into account the effect of liquid-vapor interfacial shear stress.

In 1991, Wu and Peterson [75] developed a transient numerical model capable of predicting the thermal behavior of micro heat pipes and compared their results with the steady state results obtained by Babin et al. [76] in 1990.

Notebook computers involved the first high volume use of heat pipes when Intel introduced the Pentium ® TCP packages in 1994 [77]. The main reason for the use of heat pipes is the Pentium ® power dissipation level and the limitation and constraints of space and weight in notebooks.

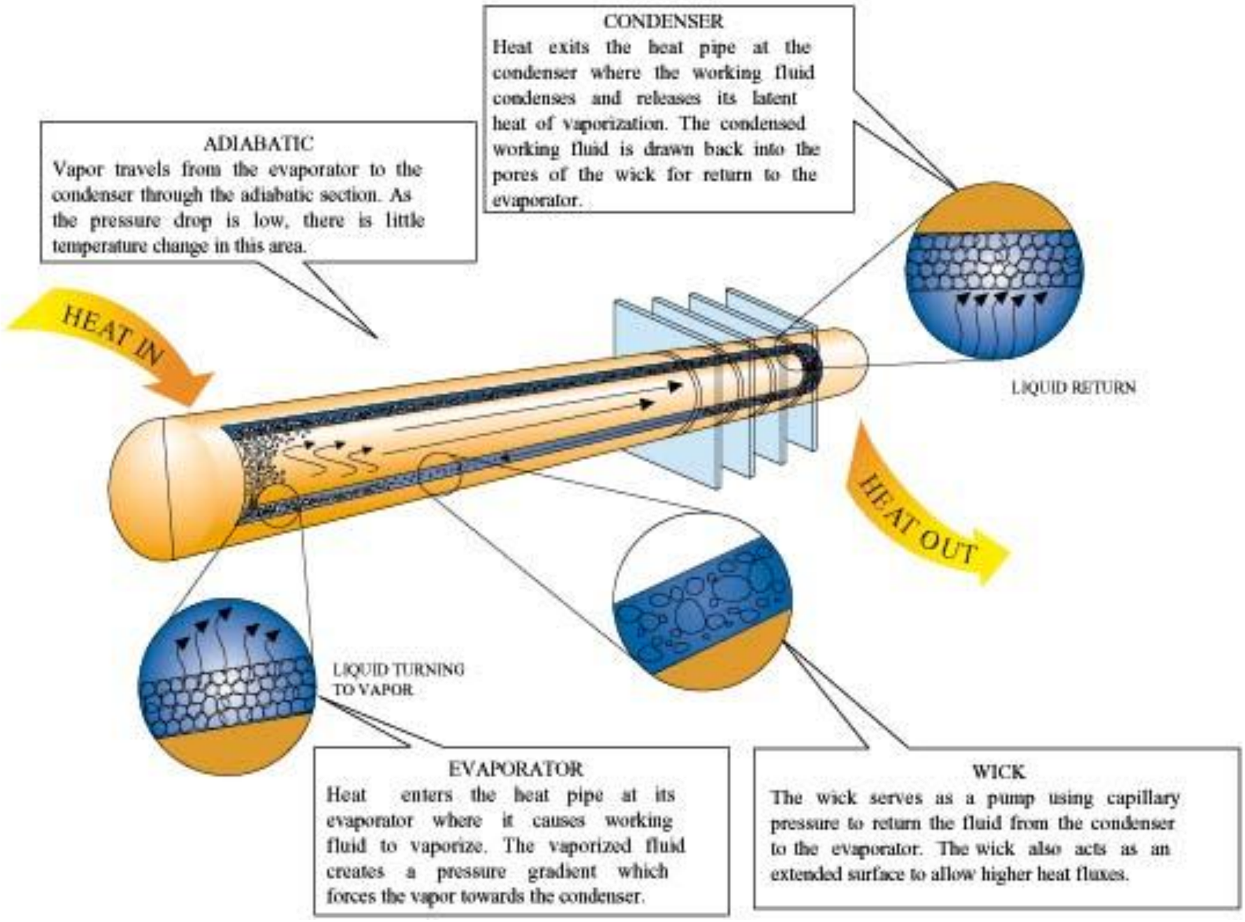
Compared to metal plates or heat sinks, heat pipes offer excellent thermal performance with much less weight and can spread the heat away from the CPU to other areas where the heat can be rejected. The performance of natural convection heat sinks is directly dependent on the effective surface area: more effective surface area results in better performance.

To enhance the heat transfer, an additional cooling fan is used with the aluminum heat sink. The increase of the microprocessor speed and number of transistors cramped into the processor core silicon die has continuously driven up its power dissipation. Heat sink sizes have been increasing in personal computers, from the 2”× 2” aluminum extrusion heat sinks for i486 to the 3”× 3” heat sinks for Pentium ® and even large heat sinks for the latest Pentium ® II microprocessors. Heat pipes, as higher level thermal solutions are naturally being investigated as the potential thermal solutions for these systems [78].

For electronic equipments, heat pipes of diameter 3 to 6 mm and length less than 400 mm are preferred [79].

Heat Pipe Operation

A heat pipe is essentially a passive heat transfer device with an extremely high effective thermal conductivity. The two-phase heat transfer mechanism results in heat transfer capabilities from one hundred to several thousand times that of an equivalent piece of copper.



ADIABATIC

Vapor travels from the evaporator to the condenser through the adiabatic section. As the pressure drop is low, there is little temperature change in this area.

CONDENSER

Heat exits the heat pipe at the condenser where the working fluid condenses and releases its latent heat of vaporization. The condensed working fluid is drawn back into the pores of the wick for return to the evaporator.

EVAPORATOR

Heat enters the heat pipe at its evaporator where it causes working fluid to vaporize. The vaporized fluid creates a pressure gradient which forces the vapor towards the condenser.

WICK

The wick serves as a pump using capillary pressure to return the fluid from the condenser to the evaporator. The wick also acts as an extended surface to allow higher heat fluxes.

Fig 2.6: Mechanism of heat pipe

As shown in Figure 2.6, the heat pipe in its simplest configuration is a closed, evacuated cylindrical vessel with the internal walls lined with a capillary structure or wick that is saturated with a working fluid. Since the heat pipe is evacuated and then charged with the working fluid prior to being sealed, the internal pressure is set by the vapor pressure of the fluid.

As heat is input at the evaporator, fluid is vaporized, creating a pressure gradient in the pipe. This pressure gradient forces the vapor to flow along the pipe to a cooler section where it condenses giving up its latent heat of vaporization. The working fluid is then returned to the evaporator by the capillary forces developed in the wick structure.

Heat pipes can be designed to operate over a very broad range of temperatures from cryogenic (< -243°C) applications utilizing titanium alloy/nitrogen heat pipes, to high temperature applications (>2000°C)using tungsten/silver heat pipes. In electronic cooling applications where it is desirable to maintain junction temperatures below 125-150°C, copper/water heat pipes are typically used. Copper/methanol heat pipes are used if the application requires heat pipe operation below 0°C.

Heat Pipe Design

There are many factors to consider when designing a heat pipe: compatibility of materials, operating temperature range, diameter, power limitations, thermal resistances, and operating orientation. However, the design issues are reduced to two major considerations by limiting the selection to copper/water heat pipes for cooling electronics. These considerations are the amount of power the heat pipe is capable of carrying and its effective thermal resistance. These two major heat pipe design criteria are discussed below.

Limits To Heat Transport

The most important heat pipe design consideration is the amount of power the heat pipe is capable of transferring. Heat pipes can be designed to carry a few watts or several kilowatts, depending on the application. Heat pipes can transfer much higher powers for a given temperature gradient than even the best metallic conductors. If driven beyond its capacity, however, the effective thermal conductivity of the heat pipe will be significantly reduced. Therefore, it is important to assure that the heat pipe is designed to safely transport the required heat load.

The maximum heat transport capability of the heat pipe is governed by several limiting factors which must be addressed when designing a heat pipe. There are five primary heat pipe heat transport limitations. These heat transport limits, which are a function of the heat pipe operating temperature, include: viscous, sonic, capillary pumping, entrainment or flooding, and boiling. Figures 2.7 and 2.8 show that capillary limit is usually the limiting factor in a heat pipe design. These are the graphs of the axial heat transport limits as a function of operating temperature for typical powder metal and screen wicked heat pipes. Each heat transport limitation is summarized in Table 2.2

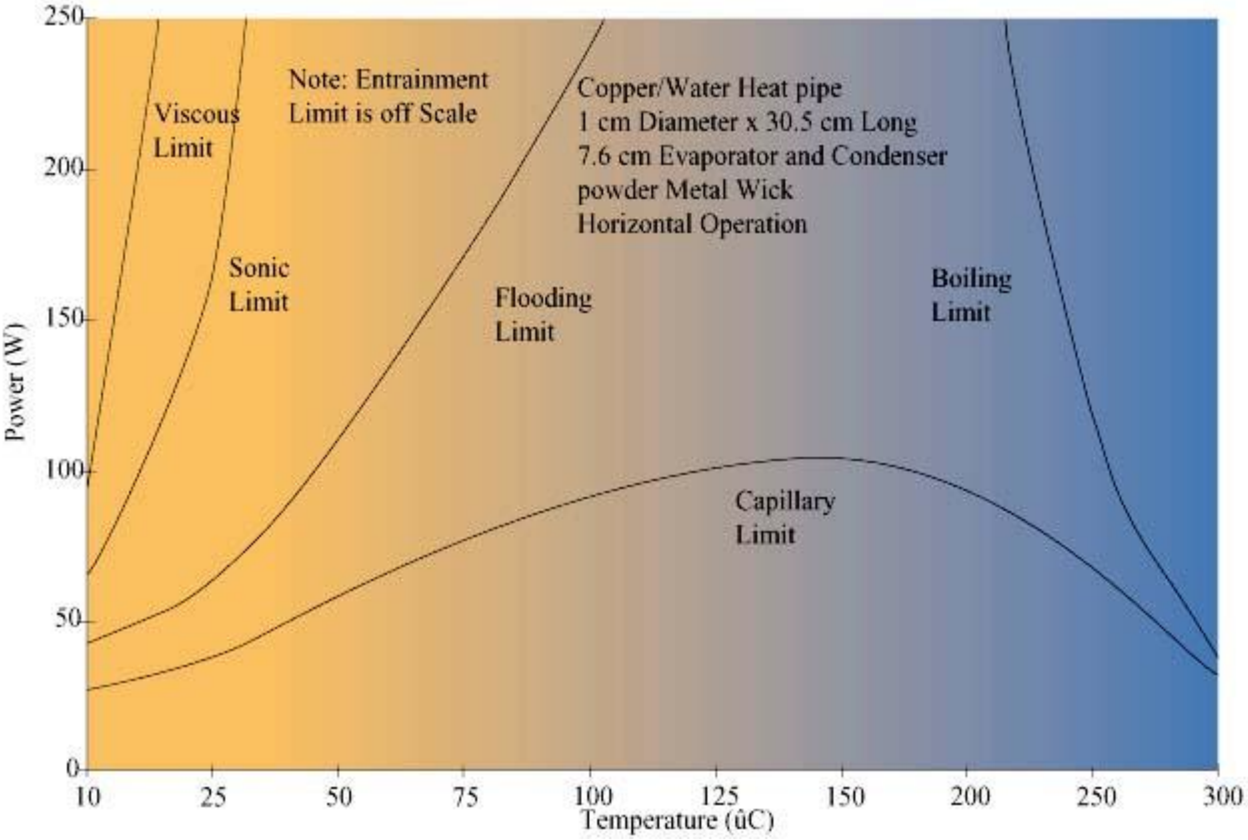


Figure 2.7: Predicted heat pipe limitations

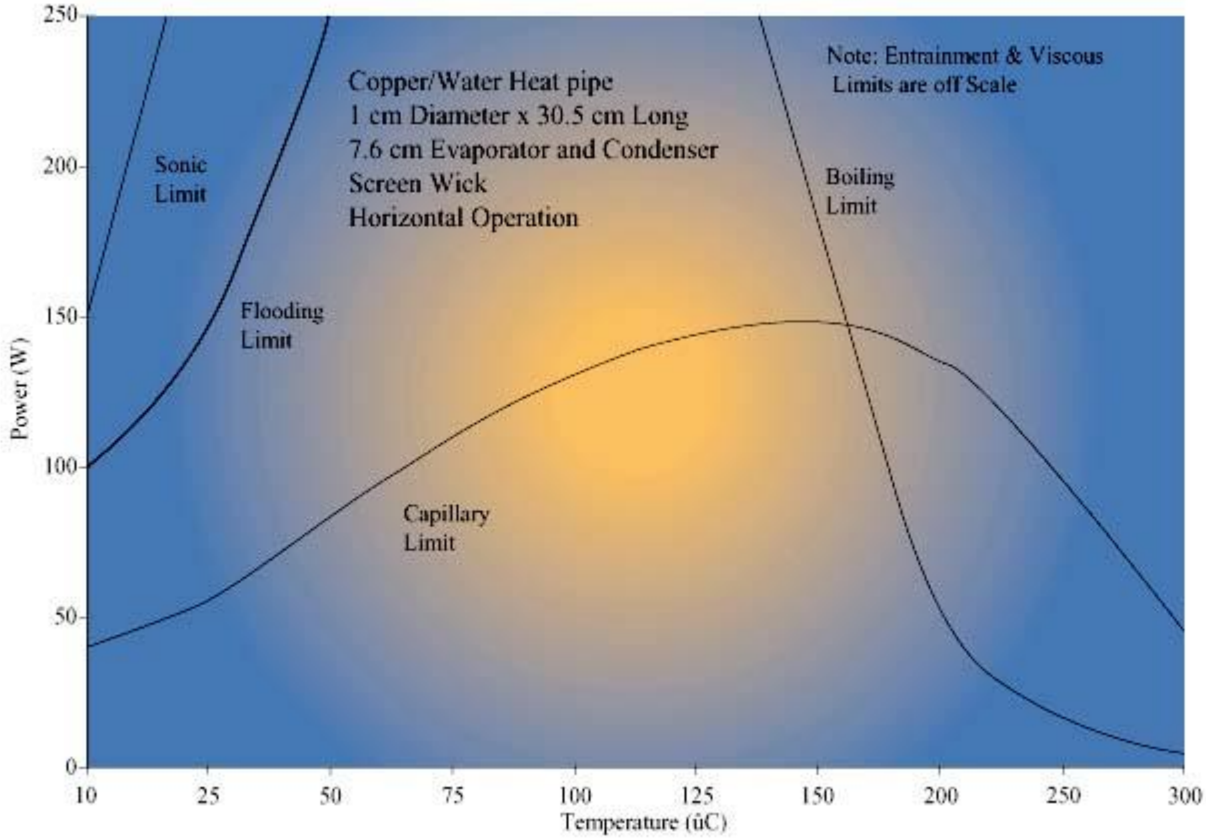


Figure 2.8: Predicted heat pipe limits

Table 2.2: Heat pipe heat transport limitations

Heat Transport Limit	Description	Cause	Potential Solution
Viscous	Viscous forces prevent vapor flow in the heat pipe	Heat pipe operating below recommended operating temperature	Increase heat pipe operating temperature or find alternative working fluid
Sonic	Vapor flow reaches sonic velocity when exiting heat pipe evaporator resulting in a constant heat pipe transport power and large temperature gradients	Power/temperature combination, too much power at low operating temperature	This is typically only a problem at start-up. The heat pipe will carry a set power and the large T will self correct as the heat pipe warms up
Entrainment/ Flooding	High velocity vapor flow prevents	Heat pipe operating above designed	Increase vapor space diameter

	condensate from returning to evaporator	power input or at too low an operating temperature	or operating temperature
Capillary	Sum of gravitational, liquid and vapor flow pressure drops exceed the capillary pumping head of the heat pipe wick structure	Heat pipe input power exceeds the design heat transport capacity of the heat pipe	Modify heat pipe wick structure design or reduce power input
Boiling	Film boiling in heat pipe evaporator typically initiates at5-10 W/cm^2 for screen wicks and 20-30 W/cm^2 for powder metal wicks	High radial heat flux causes film boiling resulting in heat pipe dry out and large thermal resistances	Use a wick with a higher heat flux capacity or spread out the heat load

The capillary limit is set by the pumping capacity of the wick structure. As shown in Figure 2.9, the capillary limit is a strong function of the operating orientation and the type of wick structure.

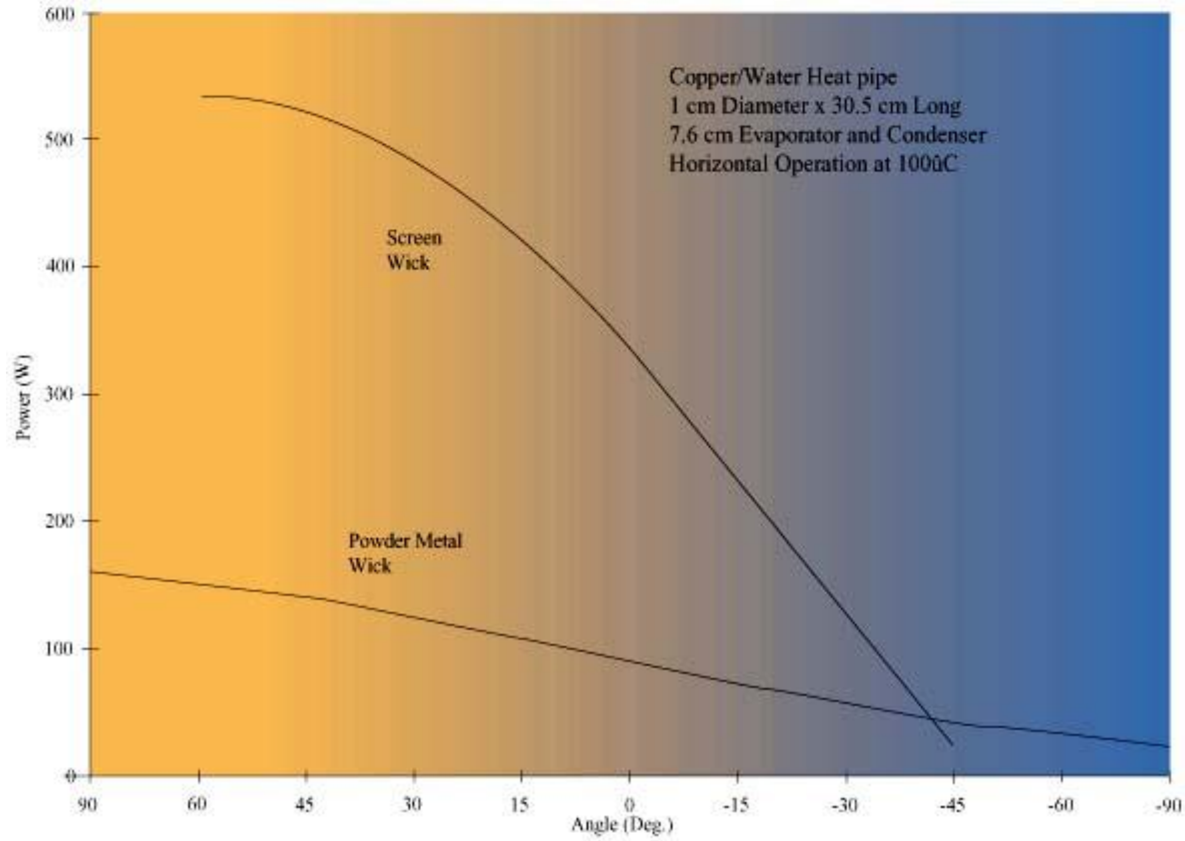


Fig 2.9: Capillary limits vs. operating angle

The two most important properties of a wick are the pore radius and the permeability. The pore radius determines the pumping pressure the wick can develop. The permeability determines the frictional losses of the fluid as it flows through the wick. There are several types of wick structures available including: grooves, screen, cables/fibers, and sintered powder metal. Figure 2.10 shows several heat pipe wick structures.

Fig 2.10: Wick structures

It is important to select the proper wick structure for your application. The above list is in order of decreasing permeability and decreasing pore radius. Grooved wicks have a large pore radius and a high permeability, as a result the pressure losses are low but the pumping head is also low. Grooved wicks can transfer high heat loads in a horizontal or gravity aided position, but cannot transfer large loads against gravity. The powder metal wicks on the opposite end of the list have small pore radii and relatively low permeability. Powder metal wicks are limited by pressure drops in the horizontal position but can transfer large loads against gravity.

Effective Heat Pipe Thermal Resistance

The other primary heat pipe design consideration is the effective heat pipe thermal resistance or overall heat pipe ΔT at a given design power. As the heat pipe is a two-phase heat transfer device, a constant effective thermal resistance value cannot be assigned. The effective thermal resistance is not constant but a function of a large number of variables, such as heat pipe geometry, evaporator length, condenser length, wick structure, and working fluid. The total thermal resistance of a heat pipe is the sum of the resistances due to conduction through the wall, conduction through the wick, evaporation or boiling, axial vapor flow, condensation, and conduction losses back through the condenser section wick and wall. Figure 2.11 shows a power versus ΔT curve for a typical copper/water heat pipe.

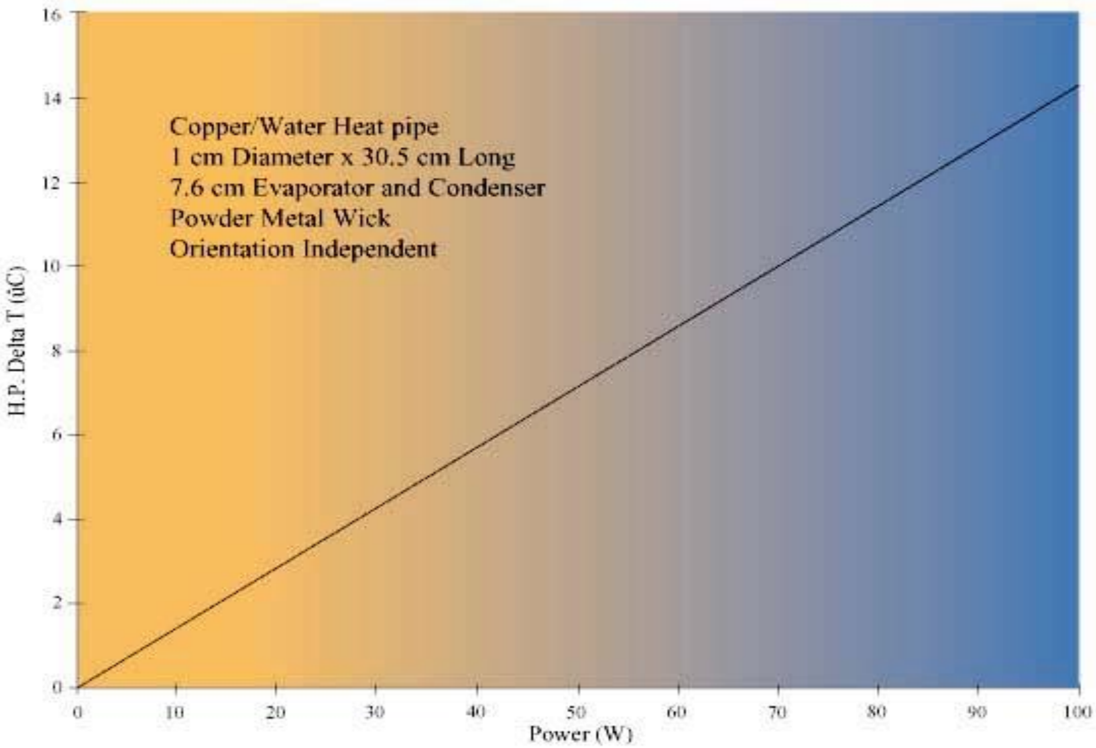


Fig 2.11: Predicted heat pipe Delta-TT

The detailed thermal analysis of heat pipes is rather complex. There are, however, a few rules of thumb that can be used for first pass design considerations. A rough guide for a copper/water heat pipe with a powder metal wick structure is to use 0.2°C/W/cm2 for thermal resistance at the evaporator and condenser, and 0.02°C/W/cm2 for axial resistance.

The evaporator and condenser resistances are based on the outer surface area of the heat pipe. The axial resistance is based on the cross-sectional area of the vapor space. This design guide is only useful for powers at or below the design power for the given heat pipe.

2.2.7 HEAT PIPE & HEAT SINK

Heat sink with heat pipes associated with a fan (Ultra-120 eXtreme, Megahalems, Megahalems Rev.B) is the most recent and efficient cooling systems these days that has been accepted by many microprocessor companies. This is better in performance than traditional heat sink and fan system.

Fig 2.12: Traditional heat sink and fan

Fig 2.13: Heat sink with heat pipes & fan

Megahalems

The Megahalems is its name, an obvious play on Nehalem, the codename for Intel's first family of Core i7 processors. If any CPU deserves a "mega" heat sink, it’s the 125W Core i7's. The Megahalems is another giant aluminum tower heat sink with a six heat pipe design. It is compatible with Intel LGA775/1366 motherboards only and does not ship with a fan.

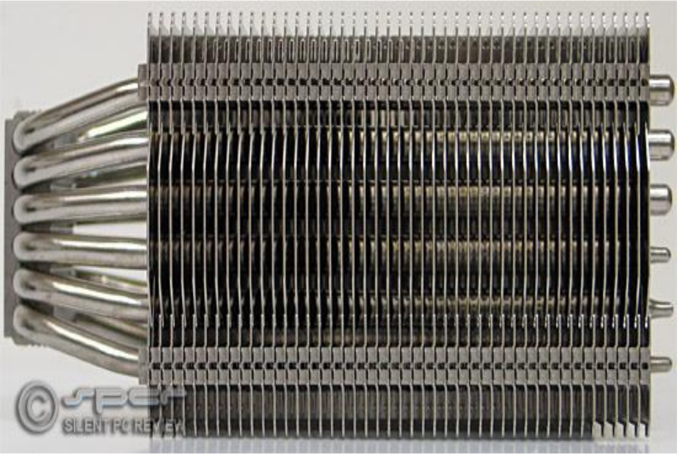


Fig 2.14: Side view of a Megahalems

Table 2.3: Prolimatech Megahalems: Specifications[80]

Heat sink Dimension	(L)130mm X (W)74mmX (H)158.7mm
Heat sink Weight	790g
Heat pipe	Ø 6mm X 6pcs
Suggest Fan	120mm X 120mm X25mm
Suggest Fan Speed	800~1200rpm
Suggest Noise Level (dBA)	Below 26dBA
Air Flow	57CFM
Direction of heat sink	Faces the rear exhaust system fan

Table 2.4: Prolimatech Megahalems: Key Features[80]

Feature & Brief	Comment
Minimal air resistance between fins allowing best balance between noise and performance in range of 800-1200RPM	This is a critical issue. Only testing will tell if they got it right.
Heat pipes are lined up in a straight line to prevent air back draft allowing air to easily pass through the heat sink body	It seems logical to stagger heat pipes to maximize their exposure to airflow, but at lower fan speeds it may do more harm than good.
Wide fins with mathematically calculated thickness to maximize best air-to-surface cooling rate	The more surface area the better.
Uniquely designed, easy-to-install socket 775 and 1366 retention mechanism to increase cooling ability.	The Megahalems is an Intel-only CPU cooler for LGA775/1366.
Easy to apply, high grade thermal compound, a perfect sidekick to all Prolimatech heat sinks	To make a proper comparison to other heat sinks our own reference thermal compound will be used.

Physical details[80]

In both size and appearance the two coolers Ultra-120 eXtreme & Megahalems are similar, though the Megahalems has a noticeable gap in the center. The heat pipes are also aligned in straight rows rather than staggered.

Fig 2.15: Ultra-120 eXtreme on the left, Megahalems on the right.

Fig 2.16: Front view

Up side close. The fins are approximately 0.50 mm thick with 2.00 mm separation. Fin spacing is about 0.60 mm wider than the Ultra-120 eXtreme and 0.60 mm narrower than the Noctua NH-U12P.

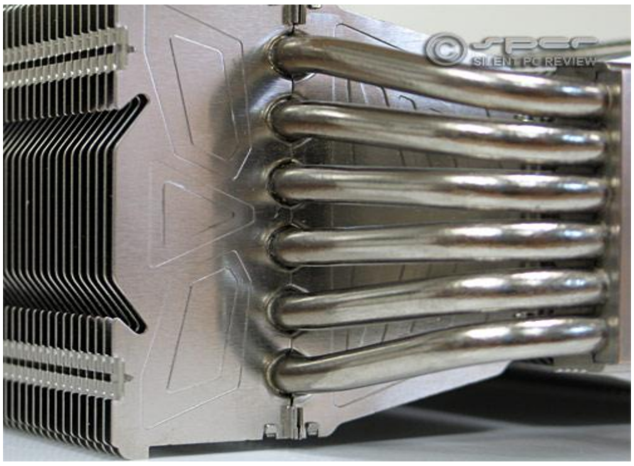


Fig 2.17: Adiabatic section

The fins are actually composed of four sections — a separating line can be seen on each side running down the length of the heat pipes. At first blush, this multi-section fin design does not seem promising, as the break in the fin is another thermal transition point where losses could occur. However, the proof is always in the cooling results.

Fig 2.18: Evaporator section

The heat pipes packed together tightly at the bottom. They are soldered to the base for better thermal conduction.

Fig 2.19: Base

The base was flat and had a very dull shine.

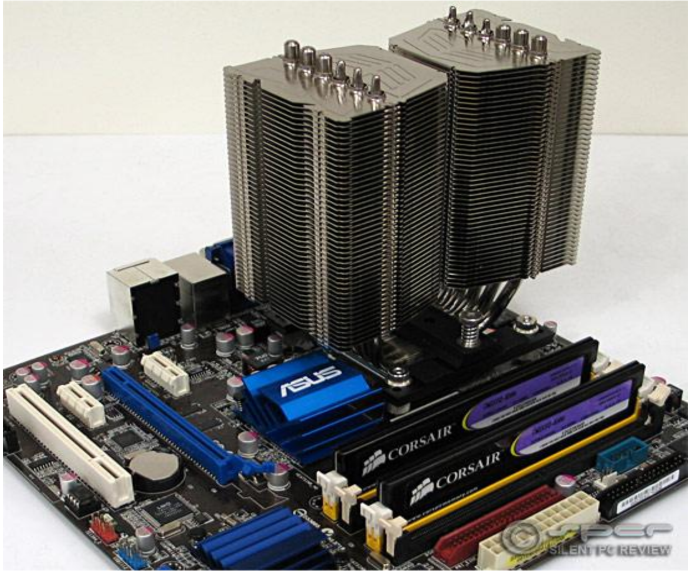


Fig 2.20: Installation

The heat sink is then placed on top of the CPU and a crossbar is fitted above the mounting plate. Large spring-loaded bolts are then screwed into the side bars. This is the only step that requires any tools — the rest is done by hand.

Fig 2.21: With fan

The supplied fan clips are designed to latch onto the outside mounting holes of a 120mm fan. The Megahalems does not come with a fan, but Prolimatech provided us with one of their own 120mm fans.

Table 2.5: Cooling Result[80]

Prolimatech Megahalems w/ provided 120mm fan				
Fan Voltage	SPL@1m	Temp	°C Rise	°C/W
12V	20 dBA	30°C	10	0.13
9V	16 dBA	31°C	11	0.14
7V	13 dBA	34°C	14	0.18
5V	12 dBA	39°C	19	0.24
Prolimatech Megahalems w/ reference 120mm fan				
12V	16 dBA	30°C	10	0.13
9V	13 dBA	34°C	14	0.18
7V	12 dBA	37°C	17	0.22
5V	11 dBA	40°C	20	0.26
Load Temp: CPUBurn for ~10 mins. °C Rise: Temperature rise above ambient (20°C) at load. °C/W: based on the amount of heat dissipated by the CPU (measured 78W); lower is better.				

The Prolimatech Megahalems delivers a championship performance, no matter how much airflow is supplied by the fan. It performs similarly to the Thermal right HR-01 Plus in a low airflow environment, but does 3°C better with high airflow, making it an all-around superior cooler. The Megahalems is a first class heat sink, but availability and price seem a bit problematic at the moment.

Megahalems Rev.B

Fig 2.22: Megahalems Rev.B

The Megahalems Rev.B is a bigger and better version of the Megahalems for Intel platforms including the new Intel LGA 1155 Socket Sandy Bridge processors. It comes with an extra set of fan clips for even better cooling results. It also includes the new all-in-one back plate for an easy, convenient installation on Intel Socket 775, 1156, and 1366. Also added to the upgrade package is the new material for the top fin on this "Mega" heat sink. This particular fin is made of all stainless steel. Its main features incorporate a greater resistance to accidental scratches and oxidation.

6 heat pipes are lined up in a straight line to prevent air back draft allowing air to easily pass through the heat sink body. Highly Efficient Fins Wide gaps between fins with mathematically calculated thickness maximize air to surface cooling rate. This efficient design minimizes air resistance between fins, allowing the best balance between noise and performance in range of. Top fin is made of scratch-resistant stainless steel to preserve shine. The Megahalems Rev.B has two sets of fan clips for a duo-fan installation. (120mm X 120mm X 25mm fan suggested)

The universal back plate with easy-to-install retention mechanism supports all Intel platforms including LGA 775/1155/1156/1366.

High Grade Thermal Compound Included Easy-to-apply high grade thermal compound is included to achieve optimal cooling performance. It’s a perfect sidekick to all Prolimatech heat sinks.

Deepcool ICE WIND heat sink and fan

Fig 2.23: Deepcool ice wind heat sink and fan

This Deepcool ICE WIND heat sink and fan deliver fast and efficient cooling for Intel or AMD processor. The MC4002IW features an aluminum fin heat sink with four copper heat pipes. For maximum cooling, the cooler comes with a large 4.72-inch (120 mm) Hydro Bearing fan with PWM function and a TPE fan cover frame that helps absorb operating vibration and noise.

The ICE Wind 400 supports a wide variety of 130W Intel Socket 1366, 1155, 1156 and 775 processors, and 125W AMD AM3, AM2+ and AM2 processors. Whether you're building a new system or upgrading an old one, this Deepcool MC4002IW heat sink and fan is the ideal companion for Intel or AMD CPU!

General Features

- Aluminum fin heat sink in a sea shape design
- 4.72-inch (120 x 120 x 25 mm) Hydro Bearing fan with PWM function (Pulse Width Modulation)
- Four (4) Copper heat pipes
- Heat pipes are lined up in a straight line to improve air flow through the heat sink
- Patented Core Touch Technology (CTT) gives it a perfect contact with the CPU surface
- TPE fan cover frame to help absorb operating vibration and noise
- Equipped with multiple clips to support Intel and AMD CPUs
- Intelligent side flow design helps improve computer case ventilation
- 17-inch 4-pin power connector
- Lead-free

Specifications:

- Fan Speed: 500 ±200 ~ 1500 ±10% RPM
- Maximum Air Flow: 66.3 CFM
- Rated Voltage: 12 VDC
- Started Voltage: 7 VDC
- Operating Voltage: 10.8 ~ 13.2 VDC
- Power Input: 1.56 W
- Rated Current: 0.13 ±10% A (max.)
- Noise: 17.8 ~ 27.6 dBA
- Heat Sink Dimensions: 6.25x5.1x2.25 inches (H x W x D, approx.)

Supported Intel Processors:

- Intel Core i7/i3/i5
- Intel Core 2 Extreme
- Intel Core 2 Quad
- Intel Core 2 Duo
- Intel Pentium Dual-Core
- Intel Pentium D
- Intel Pentium 4
- Intel Celeron Dual-Core
- Intel Celeron
- Intel Celeron D
- Socket 1366, 1155, 1156 and 775 processors with up to 130-watts

Supported AMD Processors:

- AMD Phenom II X6, X4, X3, X2
- AMD Phenom X4, X3
- AMD Athlon II X4, X3, X2
- AMD Athlon X2
- AMD Athlon FX/Athlon
- Business Class
- Sempron
- Socket AM3, AM2+ and AM2 processors with up to 125-watts

CHAPTER 3

PRINCIPLE OF THE PROJECT

3.1 RECENT WORKS ON HEAT PIPES

An experimental study is performed by Mr.Tanim et al. [81] to investigate the performance of cooling desktop processors using miniature heat pipes of 5.78 mm ID and a length of 150 mm with respect to the normal fanned CPU unit. They reported that four MHPs system shows better performance than that of two MHPs.

Another experiment has been performed similar to this one by Mr.Imtiaz and Mr.Feroz [82] on Parallel MHPs for cooling desktop computer processor. They concluded that the addition of a cooling fan in the condenser section provides the lowest temperature of the surface of the processor. This particular experiment is further development of that one.

Instead of drawing heat directly from the CPU, external variable heat source is used to observe the performance of the heat pipe under different heating conditions. Finally the performance of the MHPs is also checked for two different working fluids.

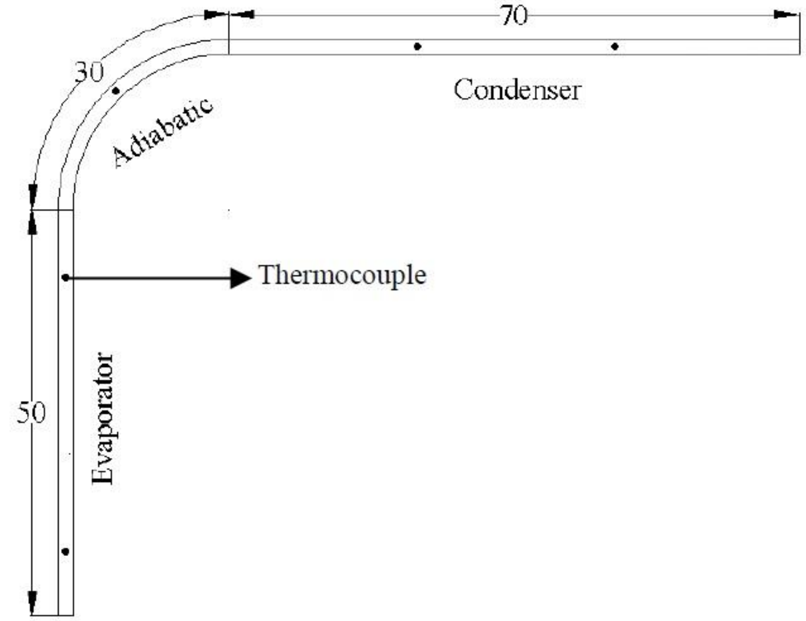


Fig 3.1: Different section of a MHPs used in early works.

3.2 SOME USEFUL DEFINITION

3.2.1 HEAT PIPES

A heat pipe or heat pin is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces.

3.2.2 EVAPORATION

Evaporation is a type of vaporization of a liquid that occurs only on the surface of a liquid.

3.2.3 CONDENSATION

Condensation is the change of the physical state of matter from gaseous phase into liquid phase, and is the reverse of vaporization.

3.2.4 LATENT HEAT

Latent heat is the heat released or absorbed by a body or a thermodynamic system during a process that occurs without a change in temperature.

3.2.5 CAPILLARY ACTION

Capillary action, or capillarity, is the ability of a liquid to flow in narrow spaces without the assistance of, and in opposition to external forces like gravity. The effect can be seen in the drawing up of liquids between the hairs of a paint-brush, in a thin tube, in porous materials such as paper, in some non-porous materials such as liquefied carbon fiber, or in a cell. It occurs because of inter-molecular attractive forces between the liquid and solid surrounding surfaces. If the diameter of the tube is sufficiently small, then the combination of surface tension (which is caused by cohesion within the liquid) and adhesive forces between the liquid and container act to lift the liquid.

3.3 PRINCIPLE OF HEAT PIPES

Heat pipes employ evaporative cooling to transfer thermal energy from one point to another by evaporation & condensation of working fluid. It relies on the temperature difference between the ends of the pipes and cannot lower temperatures at either end beyond ambient and hence they tend to equalize the temperature within the pipe.

3.4 CONSTRUCTION

A typical heat pipe consists of a sealed pipe or tube made of a material with high thermal conductivity. After evacuating, the pipe is filled with a fraction of a percent by volume of working fluid, chosen to match the operating temperature. Due to the partial vacuum that is near or below the vapor pressure of the fluid, some of the fluid will be in the liquid phase and some will be in the gas phase.

There are three sections in a typical heat pipe:

1. Evaporator section
2. Adiabatic section and
3. Condenser section

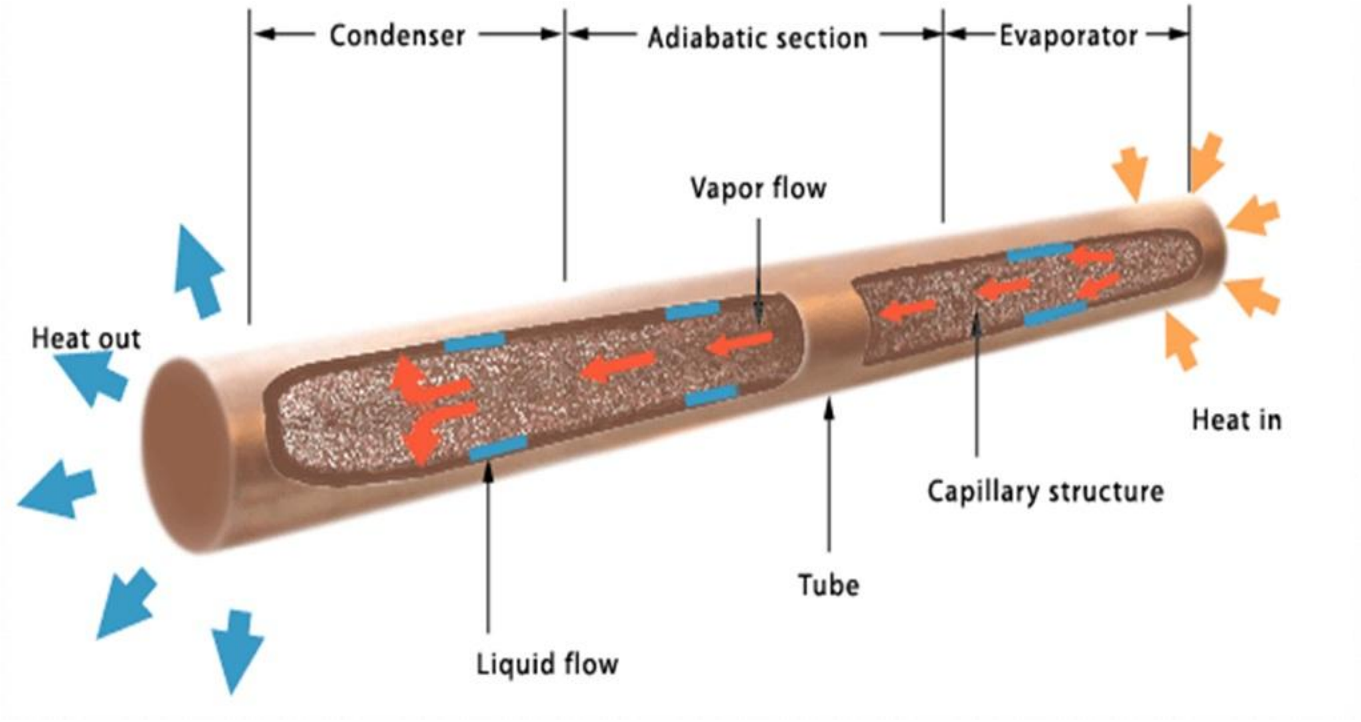


Fig 3.2: Different sections of a typical heat pipe

3.5 WORKING PRINCIPLE

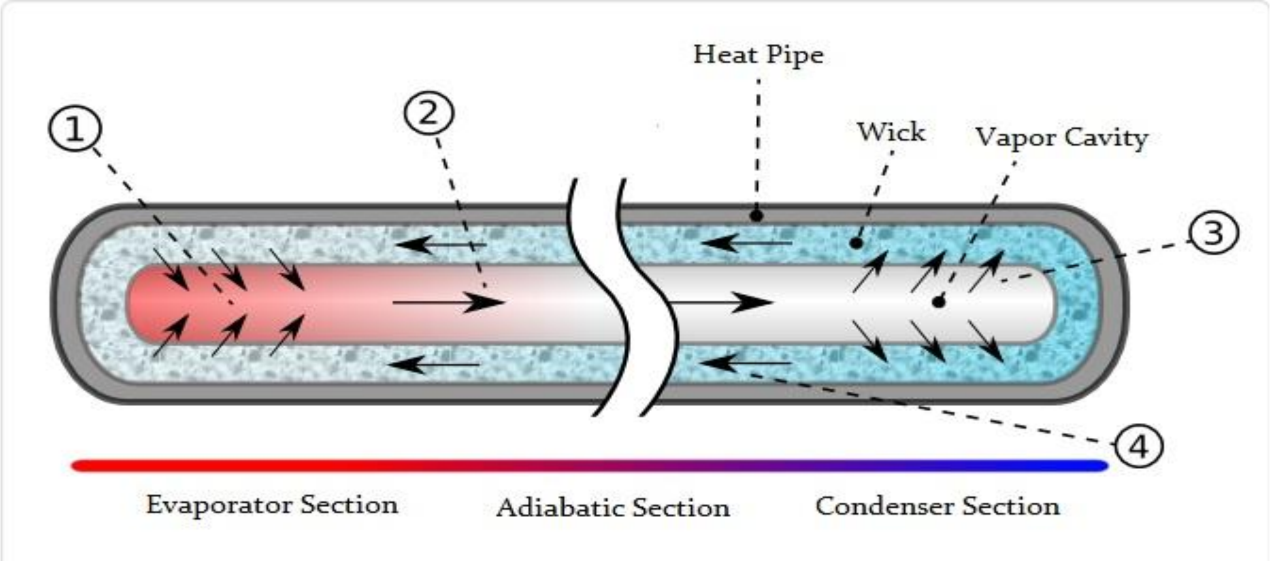


Fig 3.3: Working principle of a typical heat pipe

Heat enters the heat pipes through the evaporator section, which is typically at a very low pressure. The working fluid which is in contact with a thermally conductive solid surface, turns into vapor by absorbing heat from that surface as shown in the figure 3.3 (marked as 1) and thus reduce the temperature of the evaporation section.

The vapor pressure over the hot liquid working fluid at this section is higher than the equilibrium vapor pressure over condensing working fluid at the condenser section. This pressure difference drives the vapor towards the condenser section as shown in the figure 3.3 (marked as 2)

Vapor travels from the evaporator to the condenser section through the adiabatic section. Because the pressure drop is low, there is little temperature change in this area.

The vapor condenses back into liquid at the condenser section, releasing the latent heat of vaporization as shown in the figure 3.3 (marked as 3). The liquid then returns to the hot interface through either capillary action or gravity action as shown in the figure 3.3 (marked as 4) where it evaporates once more and repeats the cycle.

3.6 OUR OBJECTIVES

- ☐ To study the heat transfer performance of parallel micro heat pipe.
- ☐ To study the effect of different diameters on the performance of PMHPs.
- ☐ To compare the cooling performance of different diameters of PMHPs.

CHAPTER 4:

EXPERIMENTAL METHODS

4.1 EXPERIMENTAL APPARATUS

The experimental setup for this study mainly consists of

- ☐ Working fluids
- ☐ Micro Heat Pipes (MHPs)
- ☐ GI Sheet
- ☐ Electric Heater
- ☐ Digital Thermometer
- ☐ Thermocouple
- ☐ Temperature Sensor

4.1.1 WORKING FLUID

Acetone has been used as working fluid in this experiment. Acetone is an organic compound with the formula CH_3COCH_3. It is the simplest of the organic chemical called “Ketones.” It is colorless & flammable liquid with a mild pleasant odor. It is completely soluble in water. Molecular structure of the acetone is shown in figure 4.1 The properties of acetone are given in table 4.1

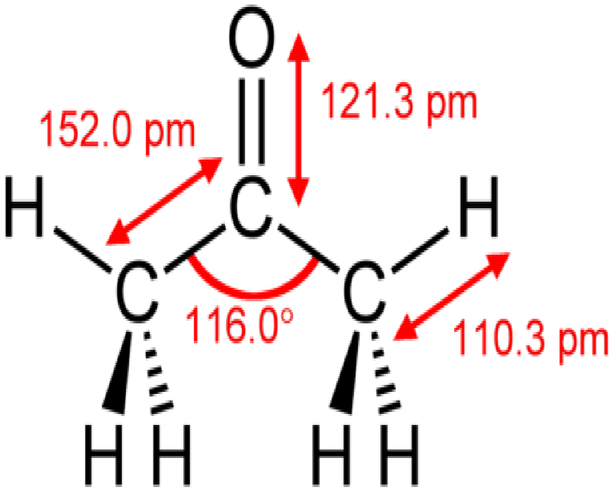


Fig 4.1: Molecular structure of acetone

Table 4.1: Properties of acetone

Properties	Acetone
Molar mass (g mol$^{-1)}$	58.08
Boiling point (K)	329-330
Melting point (K)	178-180
Prandtl number	3.77
Specific heat at constant pressure (kJ/kg K)	1.47
Specific heat at constant volume (kJ/kg K)	1.32
Liquid viscosity (μNs/m^2)	235.0
Vapor viscosity (μNs/m^2)	9.4
Density of liquid at T_{sat} (kg m^{-3})	750.0
Density of vapor at T_{sat} (kg m^{-3})	2.23
Specific heat of liquid at T_{sat} (kJ/kg K)	2.28
Specific heat of vapor at T_{sat} (kJ/kg K)	1.41
Latent heat of vaporization at T_{sat} (kJ/kg)	506.0

4.1.2 MICRO HEAT PIPES (MHPS)

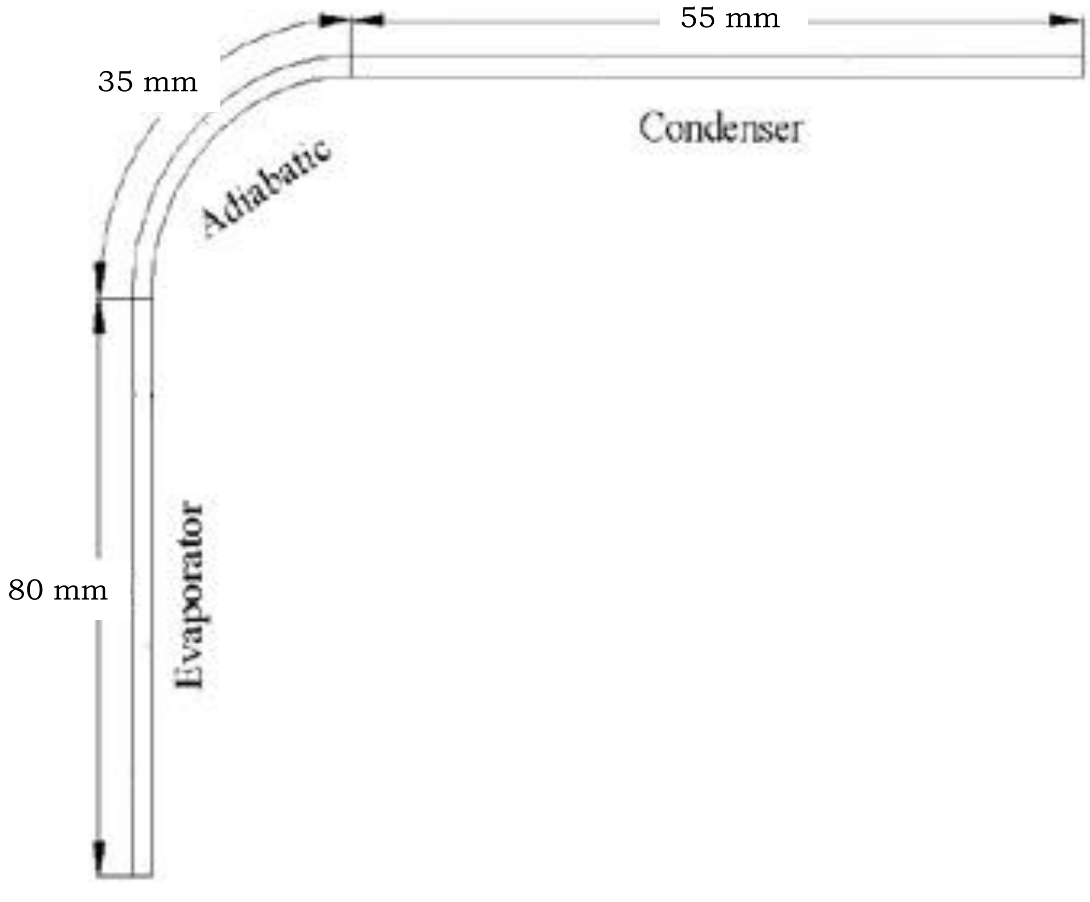


Fig 4.2: Dimension of MHPs used in this experiment

Two experimental setups are made based on different MHPs inside diameters of 2mm & 3mm. Each of these setups has six MHPs that are placed parallel to each other and with equivalent distance from one another having a length of 170 mm for cooling purpose.

There are three sections in every MHPs as shown in the figure 4.2:

1. Evaporator
2. Adiabatic and
3. Condenser

Table 4.2: Details dimension of MHPs

Parameters	Dimensions (mm)
Outside diameter of MHPs	3.2, 3.8
Inside diameter of MHPs	2.0, 3.0
Total length	170
Length of evaporator section	80
Length of adiabatic section	35
Length of condenser section	55

Evaporator section

Copper is a chemical element with the symbol Cu and atomic number 29 and having Melting point of 1357.77K. It is a ductile metal with very high thermal and electrical conductivity. The evaporator sections of PMHPs are inserted in to the grooves of copper blocks, which are placed on the top of the processor to remove the generated heat. Two copper blocks of 80mm×50mm×10mm are made very precisely to mate with the MHPs. Grooves are cut inside the blocks. The blocks are precise in dimension and surfaces are highly finished to reduce the contact resistance as well as to increase the heat transfer rate.

Heat is generated in the processor which is conducted through the copper blocks to the evaporator section of PMHPs where working fluid absorbs heat and gets vaporized.

Adiabatic section

Having the space constrain in field of its application in mind, the MHPs are bended at 90° in adiabatic section.

Condenser section

The condenser sections of PMHPs are provided with 10 numbers of copper sheets having dimension of 68mmX53mmX0.5mm placed parallel to one another as extended fins at a constant interval. Plates are welded with the PMHPs for better heat transfer.

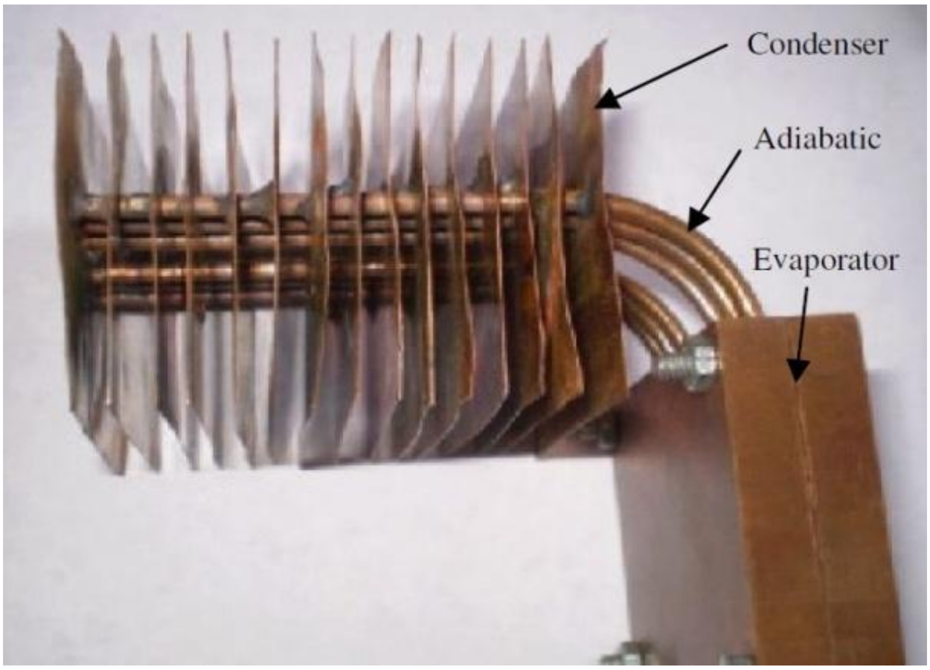


Fig 4.3: Complete setup of MHPs with evaporator, adiabatic & condenser sections.

4.2 PREPARING THE EXPERIMENTAL SETUP:

A copper block after buying from the market has been cut into two pieces. Then they are ground and machined to make room such that in between two copper blocks, MHPs can be housed. Then six copper tubes are taken, each of 170mm in length, without wick, and are placed in between the housing of the copper blocks. Two copper blocks are joined by Araldite in three sides. Then the copper tubes are slowly and carefully angled at 90° to make the adiabatic section. A copper sheet has been cut to produce ten copper small sheets that would be used as fins. This fins are then drilled accordingly so that they can be feed into the condenser section of the MHPs. The MHPs are then inserted through the holes of the fins. The fins are also fixed with the condenser section by the means of araldite glue. It requires 12 to 24 hours for araldite glue to dry. After then, acetone is charges through an injection series slowly into the MHPs one by one. Open side of the MHPs are then closed by the araldite glue. It requires checking after 24 hours and it needs to make sure that liquid is not coming out from any side.

A GI sheet is taken and prepared as figure 4.4 shown below that is to be treated as heated surface.

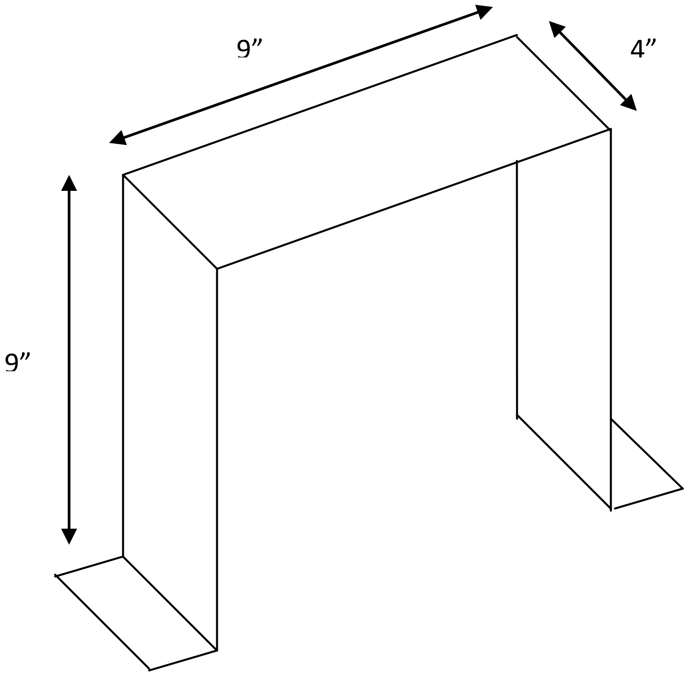


Fig: 4.4: GI sheet used as heated surface

An electric heater, digital thermometer, temperature sensor and thermocouple have been used from the workshop.

4.3 EXPERIMENTAL PROCEDURE

Four thermocouples and temperature sensors have been used for taking the temperature reading. These thermocouples are of K type (Ø=0.18mm). One thermocouple has been connected with the evaporator section, in the top surface of the copper block. Second one has been connected with the adiabatic section, in the body of MHP at the point where it makes 90° angle. Third one has been connected with the condenser section, in the surface of the top fin. Fourth one has been connected with the heated surface, in the top surface of the GI sheet.

The GI sheet has been placed over an electric heater. Then heat is supplied in the GI sheet so that it can be used as heated surface. When the temperature of the top surface of the sheet has been recorded as 56°C, heat supply from the electric heater has stopped.

Then the heated surface is allowed to be cooled by natural convection. A digital thermometer has been used to take the temperature readings of the heated surface for twelve minutes at one minute interval. Then a final reading has been recorded taking an interval of five minutes.

After that, the GI sheet is again heated up to 56°C placing over an electric heater. Then the experimental setup of PMHPs has been placed over the GI sheet. Temperature in the heated surface of the GI sheet, evaporator, adiabatic & condenser sections have been recorder for twelve minutes at one minute interval. Then a final reading has been recorded taking an interval of five minutes. A digital thermometer has been used for taking the readings. One digital thermometer has been used to check all the readings, so that thermometer errors can be avoided, if any.

During the experiment, doors and windows of the rooms are kept close to prevent wind circulation that may cause convection heat transfer from the heated surface. Also, fans are kept off. This environment has been maintained throughout the experimental procedure so that environmental errors can also be neglected.

Both the experimental setups have gone through the same procedure and the temperature readings have been recorded carefully.

CHAPTER 5

RESULTS & DISCUSSIONS

5.1 RESULTS

- ✓ It has been found that 16 minutes are required for the GI sheet to come in a temperature of 39°C from 56°C if it is cooled by natural convection. Average cooling rate is 1.06/min

- ✓ It has been found that 16 minutes are required for the GI sheet to come in a temperature of 36°C from 56°C if it is cooled by PMHPs of ID 2mm using acetone as working fluid. Average cooling rate is 1.25/min

- ✓ It has been found that 16 minutes are required for the GI sheet to come in a temperature of 38°C from 56°C if it is cooled by PMHPs of ID 3mm using acetone as working fluid. Average cooling rate is 1.13/min

- ✓ After 16 min, temperature at the top surface of the copper block has been found 46°C for PMHPs of ID 2mm.

- ✓ After 16 min, temperature at the top surface of the copper block has been found 48°C for PMHPs of ID 3mm.

- ✓ After 16 min, temperature at the adiabatic section has been found 40°C for PMHPs of ID 2mm.

- ✓ After 16 min, temperature at the adiabatic section has been found 43°C for PMHPs of ID 3mm.

- ✓ After 16 min, temperature at the top surface of the copper fins has been found 34°C for PMHPs of ID 2mm.

- ✓ After 16 min, temperature at the top surface of the copper fns has been found 34°C for PMHPs of ID 3mm.

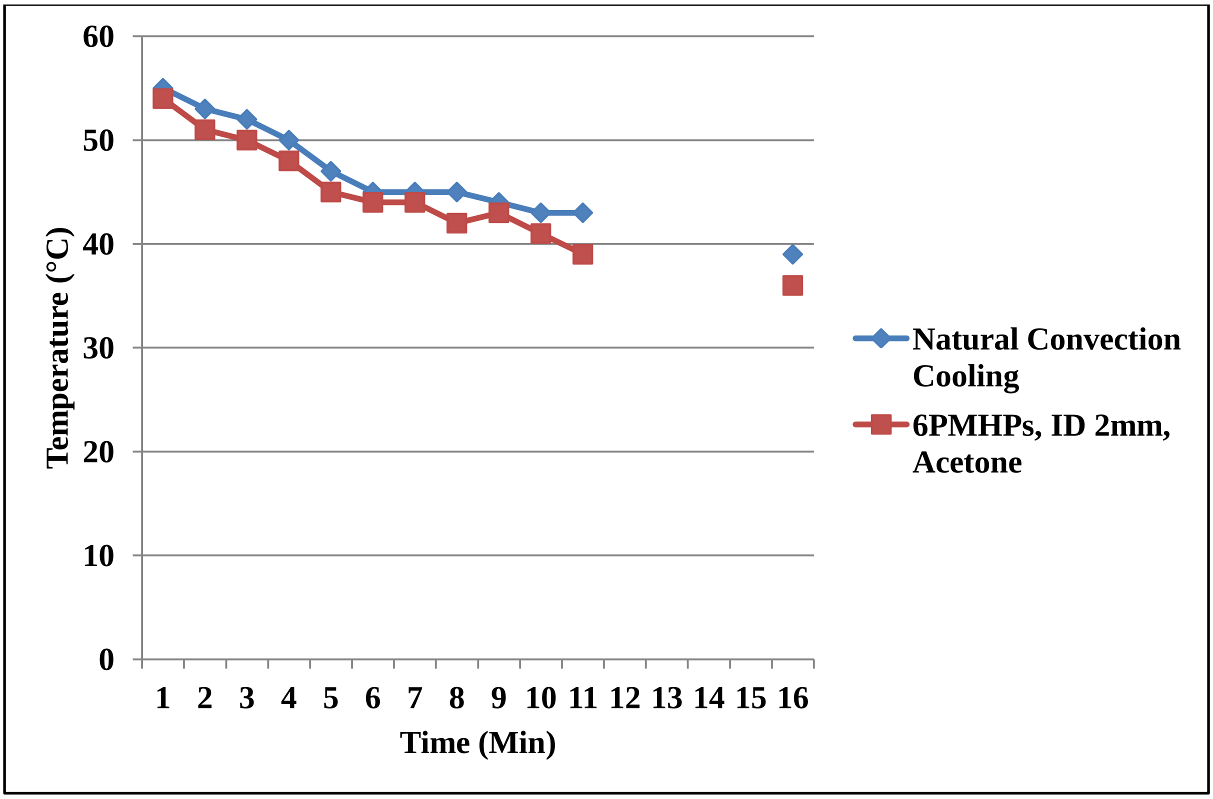


Fig 5.1: Variation of temperature with time for 6PMHPs, ID 2mm, Acetone

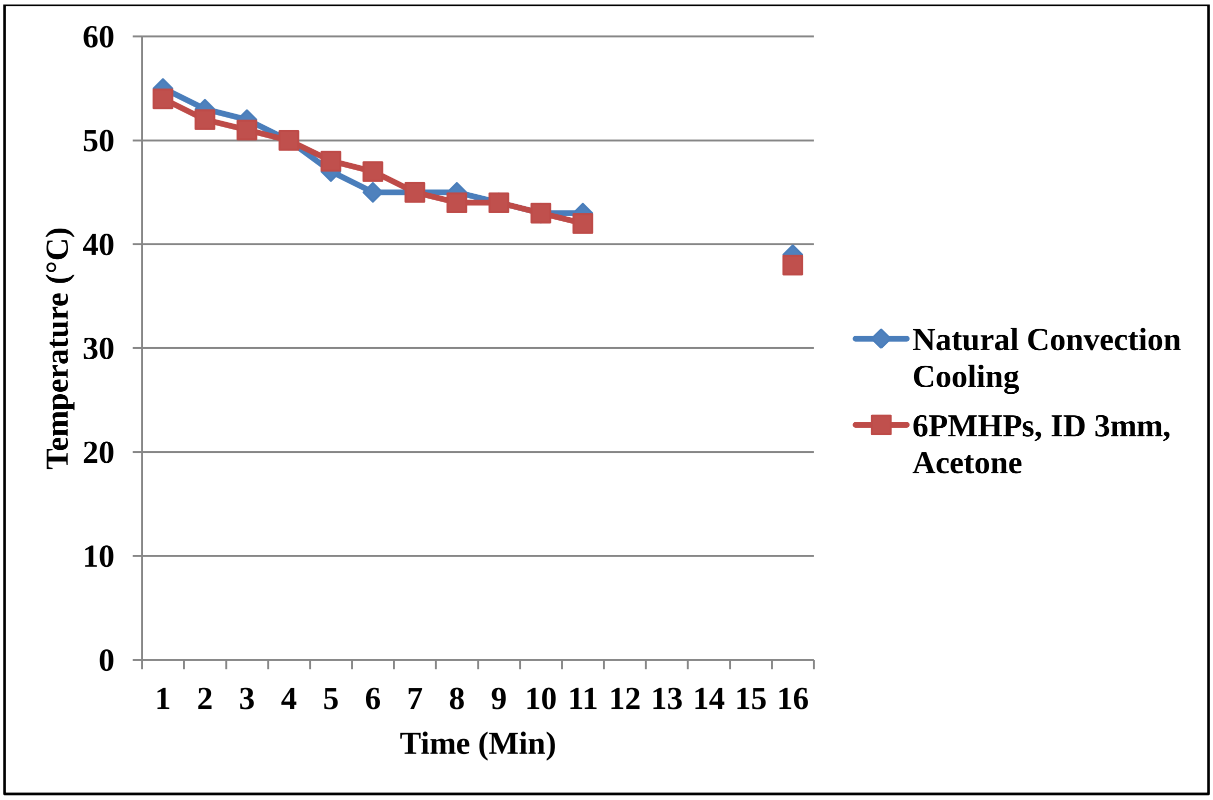


Fig 5.2: Variation of temperature with time for 6PMHPs, ID 3mm, Acetone

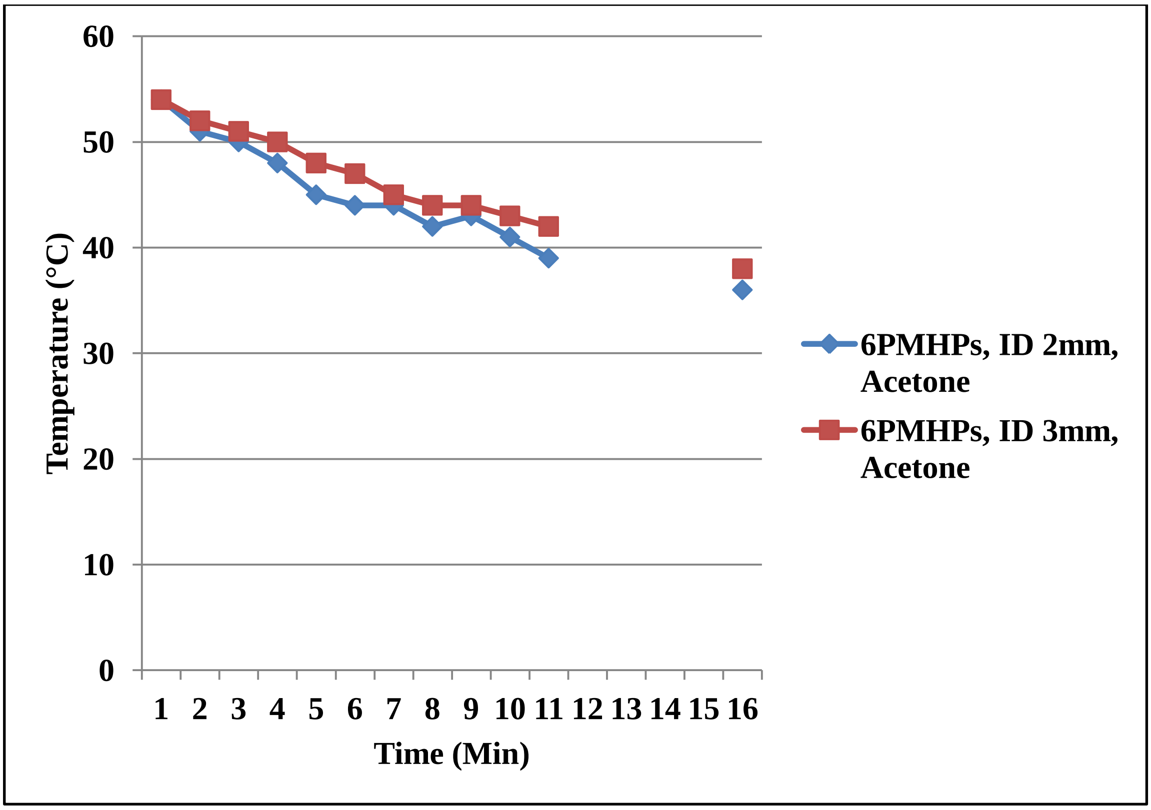


Fig 5.3: Variation of temperature with time for the metal plate

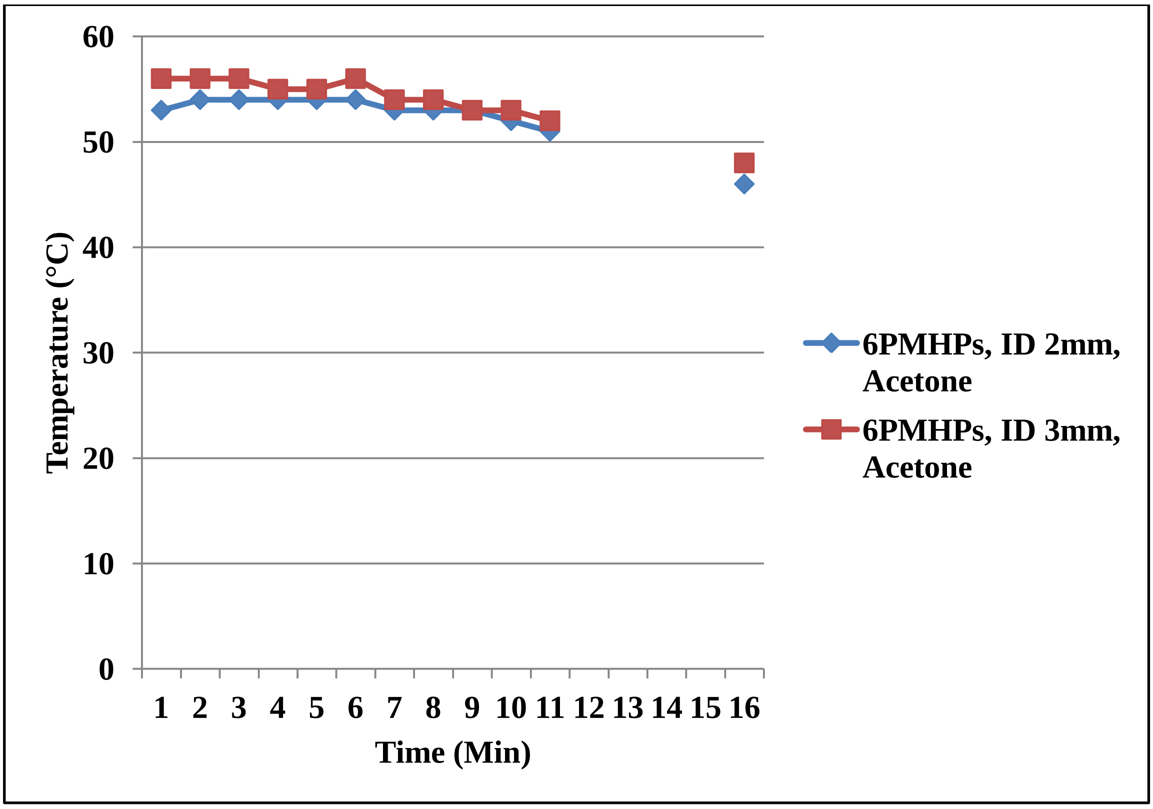


Fig 5.4: Variation of temperature with time for the evaporator section

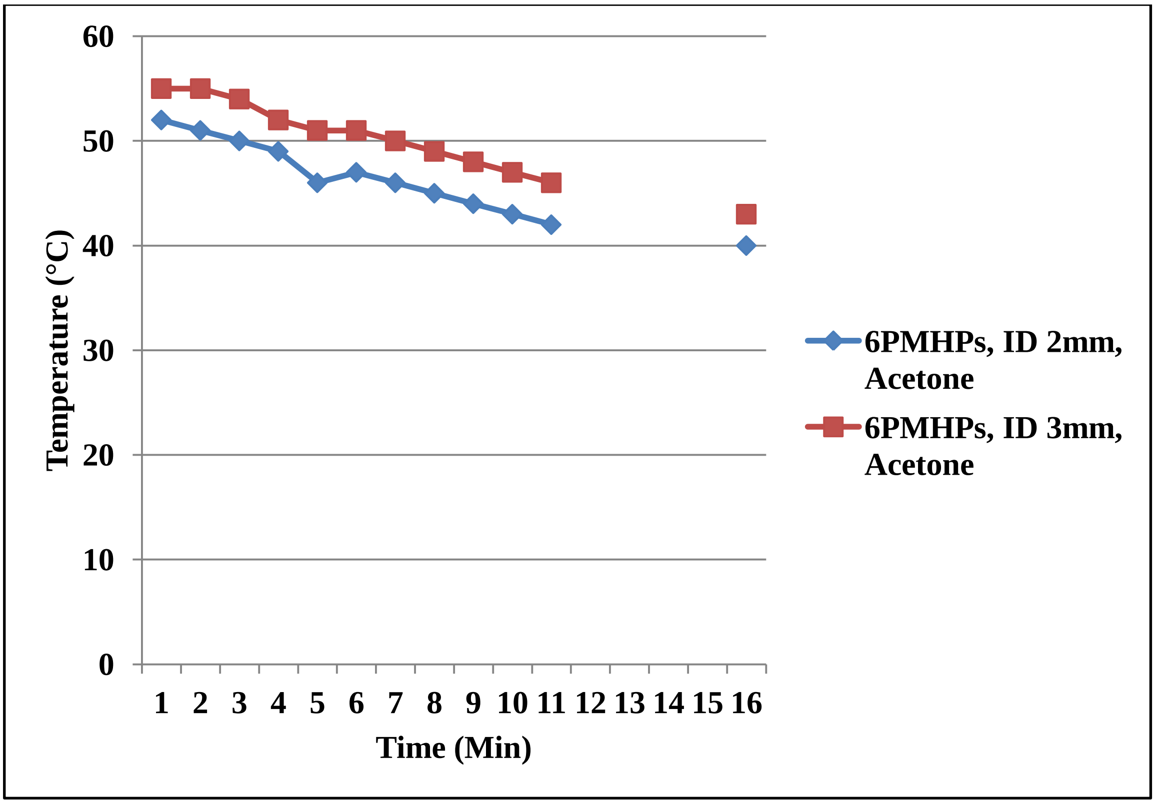


Fig 5.5: Variation of temperature with time for the adiabatic section

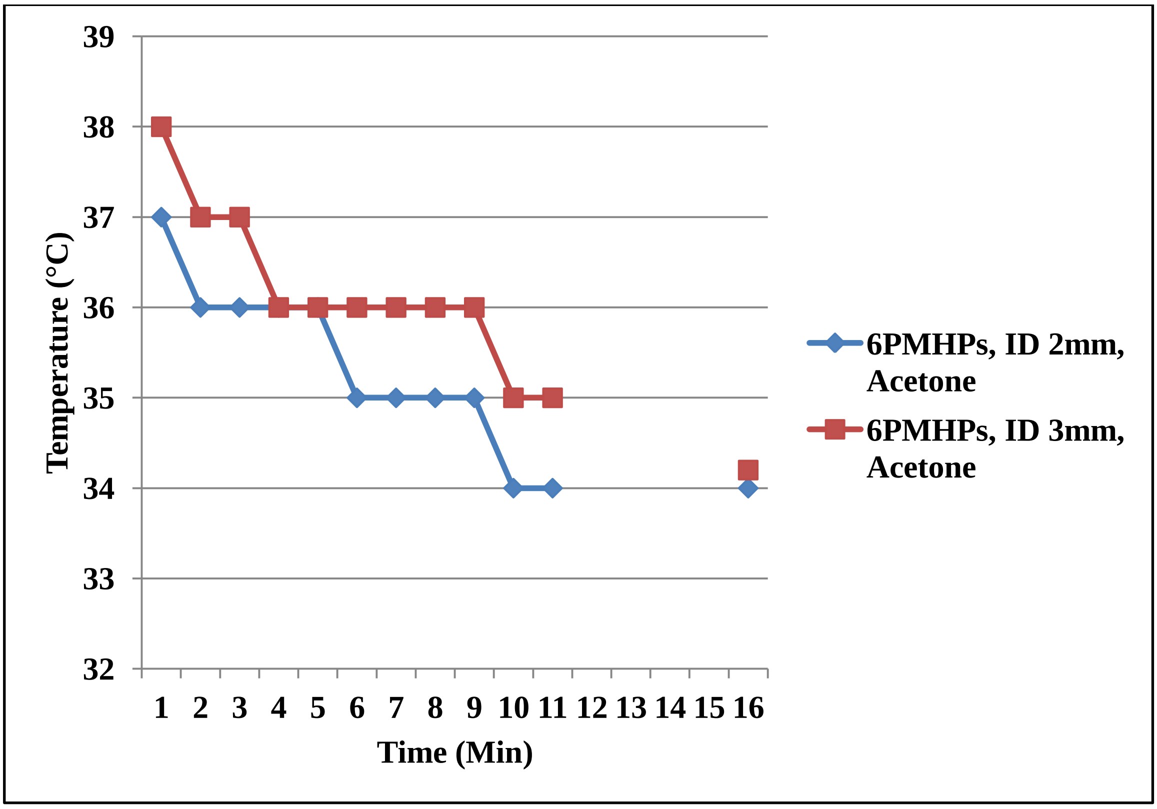


Fig 5.6: Variation of temperature with time for the condenser section

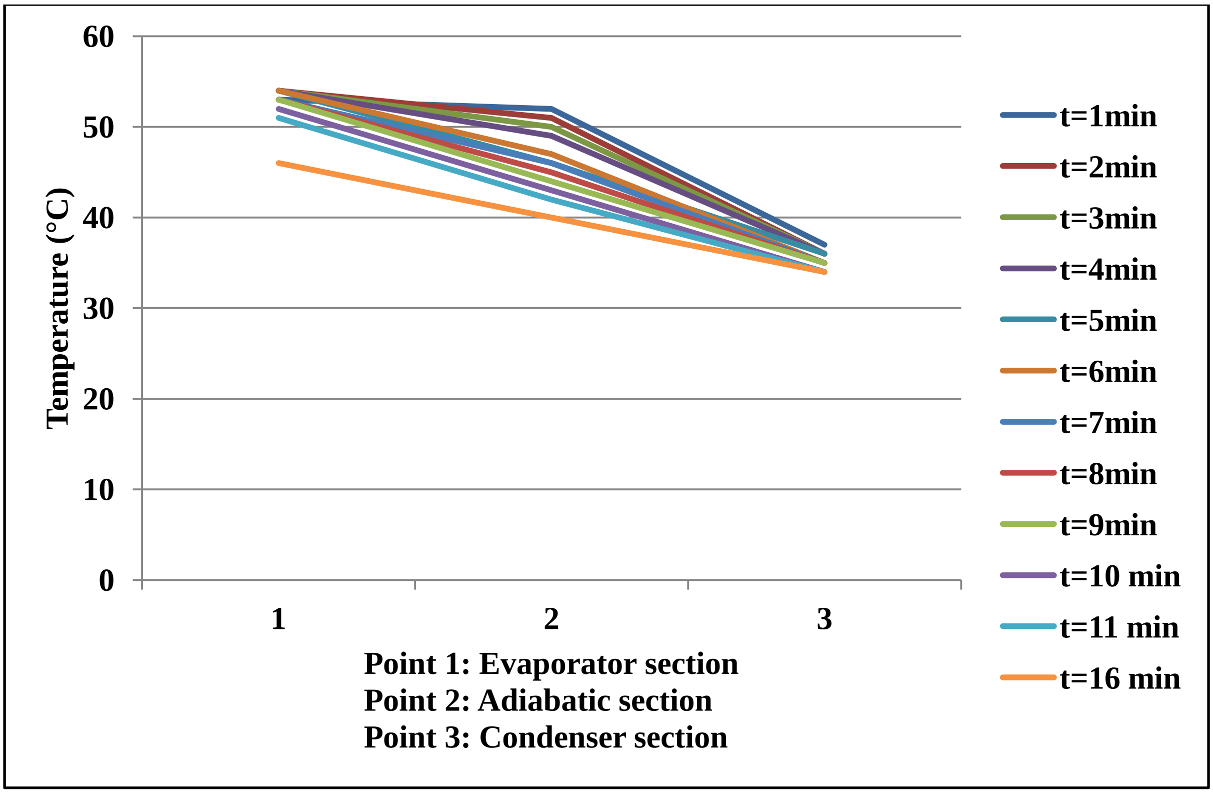


Fig 5.7: Temperature profile along the different sections for 6PMHPs, ID 2mm

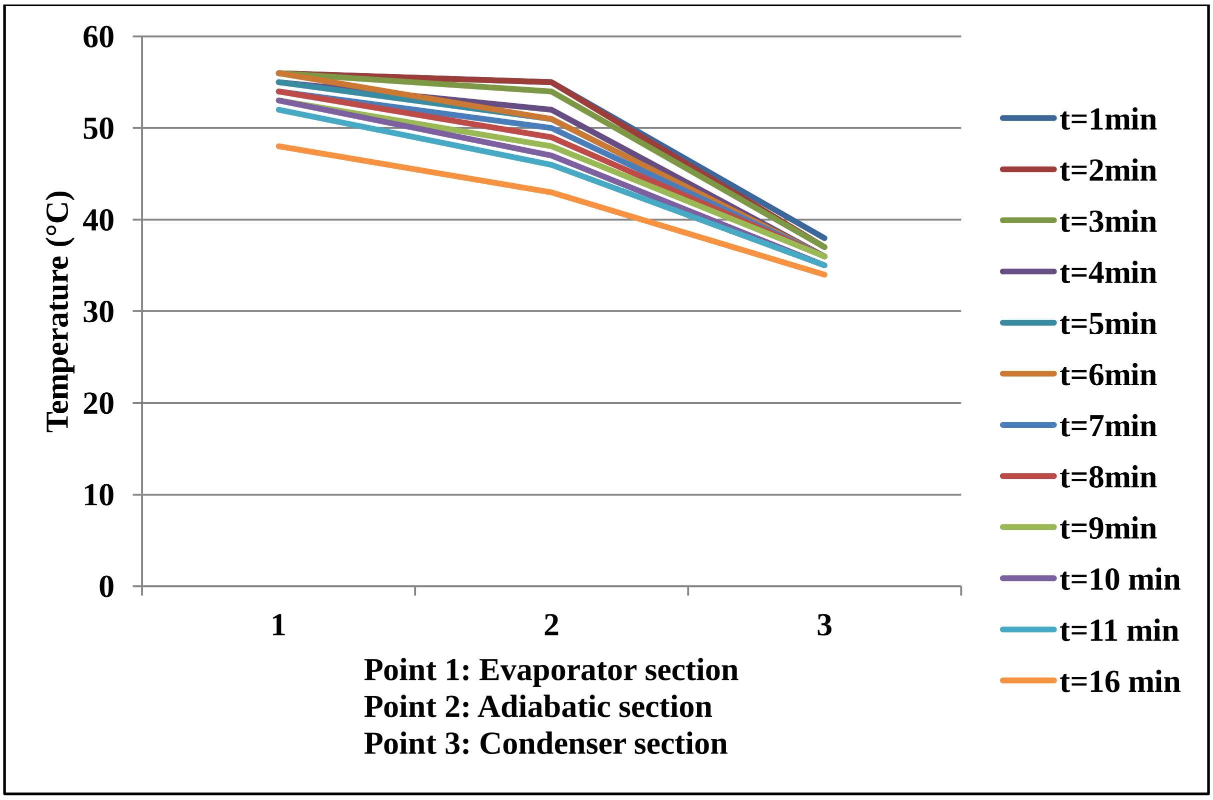


Fig 5.8: Temperature profile along the different sections for 6PMHPs, ID 3mm

5.2 DISCUSSION

- ✓ The PMHPs of ID 2mm has showed a better performance than that of ID 3mm.

- ✓ PMHPs of ID 2mm has consistently showed its performance over time.

- ✓ The experimental result could have been more appropriate, if the heated surface could be of same dimension as that of the bottom surface of the copper block.

- ✓ Surface temperature of the top fins has not been that much significant, as this fin is best and mostly exposed to the surroundings.

- ✓ The top surface temperature of the copper block is at the maximum temperature after 16 min compared to the other sections in both the cases. This is because of the conduction of heat from the GI sheet and bottom copper block to upper block.

- ✓ In this experiment, the portion of the GI sheet outside the contact of copper block has got the chance to come in contact with air, and hence some sort of natural convection could have been taken place there. But, as for the comparison, we can assume this negligible as same environmental condition exists for both the setup.

APPENDIX I

NOTES AND REFERENCES

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14) "It is reasonable to inquire, therefore, whether it is possible to devise a machine which will do for mathematical computation what the automatic lathe has done for engineering. The first suggestion that such a machine could be made came more than a hundred years ago from the mathematician Charles Babbage. Babbage's ideas have only been properly appreciated in the last ten years, but we now realize that he understood clearly all the fundamental principles which are embodied in modern digital computers"Faster than thought, edited by B. V. Bowden, 1953, Pitman publishing corporation

15) Among this extraordinary galaxy of talent Charles Babbage appears to be one of the most remarkable of all. Most of his life he spent in an entirely unsuccessful attempt to make a machine which was regarded by his contemporaries as utterly preposterous, and his efforts were regarded as futile, time-consuming and absurd. In the last decade or so we have learnt how his ideas can be embodied in a modern digital computer. He understood more about the logic of these machines than anyone else in the world had learned until after the end of the last war" Foreword, Irascible Genius, Charles Babbage, inventor by Maboth Moseley, 1964, London, Hutchinson

16) In the proposal that Aiken gave IBM in 1937 while requesting funding for the Harvard Mark I we can read: "Fewcalculating machines have been designed strictly for application to scientific investigations, the notable exceptions being those of Charles Babbage and others who followed him ... After abandoning the difference engine, Babbage devoted his energy to the design and construction of an analytical engine of far higher powers than the difference engine ... Since the time of Babbage, the development of calculating machinery has continued at an increasing rate." Howard Aiken, Proposed automatic calculating machine, reprinted in: The origins of Digital computers, Selected Papers, Edited by Brian Randell, 1973,ISBN 3-540-06169-X

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