CHAPTER – 1

INTRODUCTION

1.1 Jet impingement cooling

In the present scenario of many advanced technologies, use of electronic equipment has become almost inevitable. This electronic equipment plays a vital role in many critical areas of technology and resulted in high density of components in small volume. Therefore, there has been a steady increase in heat dissipation rate from electronic components for the last few decades. Optimization also led to greater power in the components and there is a considerable increase in the heat dissipation of electronic components. Various scientists and researchers mostly used the concept of forced convection flow to remove heat at the surface of the components.

It is necessary not only to maintain low temperatures of components but also avoid hot spots. For the improvement in the integrated circuit design for greater heat transfer area is almost impossible. Only way out seem to be development of unconventional forced convection cooling methods like impingement jets. This method looks attractive since the cooling can be directed towards the hot components and advantage of impingement jets is that it is very effective with system, where the electronic component density is high.

The importance of considering impingement jets in cooling of electronic components in which advancements in heat transfer rates
relies on the ability to dissipate large heat fluxes with high yielded load and averaged heat transfer coefficients.

Jet impingement cooling is a mechanism of heat transfer by means of collision of fluid molecules on to a surface. The impinging jet is defined as a high-velocity jet of cooling fluid forced through a hole or slot which impinges on the surface to be cooled, which results in high heat transfer rate between the wall and the fluid. Heat transfer takes place due to the collision of high velocity fluid molecules on to the surface. Fig. 1.1, shows the characteristic feature of the flow arrangement in different regions for heat transfer between the wall and the fluid.

Fig. 1.1 Schematic layout of an impinging jet
It is possible to readily move the jet to the location of interest and remove a large amount of high heat generated. Large amount of heat can be easily removed. Hence this technique can provide an effective means of removing localized heat loads, which increased the life of electronic components such as resistors and capacitors. McMurray et al.\textsuperscript{71}(1966) conducted an experimental study on convective heat transfer to an impinging plane jet from a wall with uniform heat flux. They had developed heat transfer correlations for the stagnation flow in the impingement zone and in the flat plate boundary layer region.

The semiconductor industry has developed very rapidly in the last twenty years and the sizes of electronic components have become very small and compact. New technologies have been introduced and optimizations of the systems have been accomplished. This has resulted in the enhancement of power density and heat dissipation of the components.

For example, most of the electronic components like resistors and capacitors operate only within a small range of temperatures. Hence it has become necessary to increase the heat dissipation capacity considerably. Obviously that the traditional natural and forced cooling methods have become insufficient. In this situation, the air jet impingement has turned out to be an attractive and potential alternative due high heat transfer rates.
In some applications rapid and uniform heating or cooling of the material becomes necessary. The high heat transfer rates that occur in the impingement regions of the jets can be very useful in such applications. The thermal management of electronic components like computer processors, radio transmitters, and optical devices require a reliable heat exchange system for efficient operation. Hence, impinging jets could be a good choice.

Presently, the rate of heat fluxes in any typical electronic component is about 70 W/cm², which is a common high-end commercial application. In the coming years, this value is expected to above 120 W/cm². Developments and improvements of present cooling system for these future applications will be almost impossible as they require very intricate cooling circuits. The impinging jet technique is very quite simple and moderate, is expected to provide a workable solution.

If the heat produced from an electronic component is not distributed uniformly and removed, it will heat up to unsafe temperatures, causing damage and ultimate failure of the component. It is observed that life expectancy of some of the components like silicon devices, resistors, and capacitors can be roughly doubled for every 10°C reduction in the operating temperature.
1.2 Comparison of impingement jets

Fig. 1.2(a) and 1.2(b) show possible different flow configurations of impingement jets. It could be either a submerged impinging jet or a free impinging jet. For submerged jets, it is observed, from Fig. 1.2(a), that a shear layer forms at the interface between the jet and surrounding fluid. This shear layer is unstable and it generates turbulence. But, for free jets, Fig.1.2 (b), due to instability, the turbulent motion in the shear layer does not have any substantial effect on the flow.

![Fig. 1.2 Schematic view of the (a) Submerged Jet and (b) Free Impingement Jet](image)
The impinging jets can be classified by their boundary as confined or unconfined flow field types are shown in Fig 1.3(a) and Fig.1.3 (b). Earlier studies were mostly concerned with unconfined impingement jets. Later the confined jets, where the radial spread of the jet is bounded by a confinement plate, has been investigated extensively in literature due to its importance in industrial applications.

Fig.1.3 Schematic view of the (a) Un confined impinging jet (b) Confined impinging jet
Ichimiya and Yamada\textsuperscript{47}(2003), noticed that the presence of the recirculation regions on both impingement and confinement surfaces for low spacings. It is found that the increase in Reynolds number and nozzle-to-plate spacing, the recirculation flow on the impingement surface moves downstream and its volume increases progressively.

Sadd et al.\textsuperscript{90}(1992), experimentally proved that the heat transfer data obtained with unconfined jets cannot be used reliably for design of confined jets. Chalupa et al.\textsuperscript{20}(2001), investigated experimentally the presence of the recirculation region at the confinement wall can lead to a secondary peak in Nusselt numbers which is associated with the increase of the turbulence levels adjacent to wall. Two important differences between unconfined and confined jets that affect the local heat transfer rates are the entrainment of the pressure distribution and ambient air.

1.3 Applications of jet impingement cooling

Jet impingement cooling process is encountered in a number of industrial applications. Examples are,

(a) The annealing of synthetic and metal sheets,

(b) Paper products, and drying of textile,

(c) Tempering and decisive of glass,

(d) The cooling of heated components in gas turbine engines and

(e) Chilly of hankie in cryosurgery.
In industrial electronic cooling systems, an important goal is to reduce the temperature of electronic components as quickly as possible to prevent damage or failures, which in turn increase this reliability of the electronic components. Different cooling methods have been used in impingement cooling system like direct liquid spray cooling system, indirect liquid spray cooling system and fan cooling system. Each cooling method has its own advantages and disadvantages.

Rapid cooling methods increase components safety, and improve the efficiency of the components. Rapid cooling is mostly obtained by forced cooling systems, in forced cooling; heat transfer coefficient (h-value) has to be as high as possible to reduce the cooling time. The heat transfer coefficient may vary along the surface of the electronic component affecting the external temperature distribution.

1.4 Types of flow domains

The flow domain in an impinging jet is divided into three different regions shown in Fig 1.4. They are,

(a) The jet region,

(b) The stagnation region, and

(c) Wall jet region.

The flow in the free jet region is axial in direction and is not affected by the presence of the impingement region.
Deshpande and Vaishnav (1982) experimentally investigated that the fluid issuing from the nozzle mixes with the quiescent surrounding fluid and creates a flow, which is up to a certain distance from the wall identical with the flow domain of a submerged non-impinging jet. The jet flow is un developing at different nozzle diameters from the nozzle tip.

In most applications, the nozzle-to-plate distance is too small to enable the developed jet flow condition. A shear layer forms around the jet. Its properties depend strongly on the nozzle type.

Fig. 1.4 Depicting various regions of a jet impingement
In most situations, the shear layer is initially relatively thin compared to the nozzle diameter. Therefore its dynamic behavior is similar to that of a plane shear layer. As the shear layer thickness becomes comparable with the jet diameter downstream and the behavior of the layer changes considerably.

The flow issuing from the nozzle is either laminar or turbulent, depending on type of the nozzle and the Reynolds number. The initial laminar flow undergoes transition to turbulent flow. The transition begins in the unstable shear layer. The roll-up of vortices is the first stage of this transition for moderate Reynolds numbers. The vortices are transmitted downstream by the flow. They grow pair, lose symmetry, and finally break up in eddies and a turbulent flow is developed. In many practical situations, the nozzle-to-plate spacing is small and the jet will be in a transitional state when it impinges on the wall.

Fig. 1.5 shows that at the exit of the nozzle, the emerging jet might pass through a region which is sufficiently far from the impingement surface to behave as a free submerged jet. Here, the velocity gradients in the jet create a shearing at the edges of the jet. This gradient which transfers momentum laterally outward, pulling additional fluid along with the jet and raising the jet mass flow rate. In this process, the jet loses energy and the velocity profile become flatter. A collection of equations has been established by Martain (1977), for predicting the velocity in the free jet and decaying jet regions based on low Reynolds number flow.
If the velocity profile in the nozzle exit is sufficiently flat, a potential core is formed in the centre of the jet. It is the flow region, in which the mean velocity is still the same as that at the nozzle exit. In this region, the fluid inside the core has not yet transferred its momentum to the surroundings.

Ma and Bergles\textsuperscript{74}(1990) experimentally investigated the core region. They found that stagnation Nusselt number increases slightly with increase in H/d ratio for different values of Reynolds number. However, the instantaneous velocity is not constant in the core. The flow is pulsating due to the velocity induction from the vortices passing in the shear layer. The potential core flow has an inviscid character.

Fig. 1.5 Schematic view of the flow field of a free submerged jet
1.5 Studies on reliability of electronic components on temperature

Heat transfer studies reveal that the importance of temperature on reliability of electronic components. The reliability parameter decreases by ten percent for a temperature rise of increment by 2°C. For any typical electronic component the maximum allowable temperature is about 125°C. However, the lower design limit is commonly available due to maintain the lower design limit and to fulfill the reliability criteria especially in air jet impingement cooling of electronic components.