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Heat Transfer Enhancement by Using Nanofluid Jet Impingement- a Review

Mr. Yatendra Dayal[a], Prof. Amitesh Paul[b],

[a]PG Scholar, Department of Mechanical Engineering, AGNOS College of Technology, M.P, India.
[b]Prof, Department of Mechanical Engineering, AGNOS College of Technology, M.P, India.

ABSTRACT

Fluid heating and cooling play very important roles in many industries including power generation, production processes, transportation and electronics. Nanofluid heat transfer is an innovative technology which can be used to enhance the heat transfer. The term nanofluid refers to a new kind of fluid produced by suspending nanoparticles in the base fluid. A novel approach to engineering fluids with better heat transfer properties based on the rapidly emerging field of nanotechnology has recently been proposed. In particular it was demonstrated that solid nanoparticle colloids (i.e. colloids in which the grains have dimensions of 10-40 nm) are extremely stable and exhibit no significant settling under static condition even after week or months. Impinging liquid jet is an established technique to provide high local heat transfer coefficients between the impinged liquid and a surface. This review reports research on liquid impingement jets and the abilities, limitations and features of this method of heat transfer.

Keywords – *Nanofluid, Liquid Jet Impingement, Heat Transfer.*

1. INTRODUCTION

Fluid heating and cooling plays a vital role in many industries including power generation, production processes, transportation and electronics. Heat transfer can be enhanced using different methods such as extended surfaces (fins), vibration of the heated surfaces, injection or suction of the fluid and applying electrical or magnetic fields. Nanofluid heat transfer is an innovative technology which can be used to enhance the heat transfer. The term nanofluid refers to a new kind of fluid produced by suspending nanoparticles in the base fluid. Impinging liquid jet is an established technique to provide high local heat transfer coefficients between the impinged liquid and a surface. This cooling technique is considered as an attractive cost effective method of cooling [1]. Combining the liquid jet impingement and the nanofluid technologies is thought to capture the advantages of both and consequently enhances the heat transfer significantly. Enhancing the heat transfer means compact size and low weight which reduces the cooling system capital cost.

Liquid jets can be classified as submerged or free surface. A submerged jet is formed when a liquid jet is discharged into the same liquid medium. A free surface jet is formed when a liquid jet is discharged into a gas medium. For free surface jet, the liquid jet impingement has demonstrated high cooling capacity as reported by Liu and Lienhard [1], Lienhard and Hadeler [2]. The Jet impingement or free surface flow can be classified according to jet orientation, surface type or flow type as vertical or horizontal, flat or curved, and single or two phase flow, respectively. Impinging jets can be classified as either free surface or submerged. Submerged jets exude into a space containing the same liquid at rest and can be configured as confined or unconfined, depending on the jet-to-target distance. In a submerged configuration, the interaction of the issuing jet and the stagnant fluid leads to entrainment in the shear zone and the development of a potential core near the jet centerline.

In a free-surface jet configuration, the fluid is discharged from the nozzle into an ambient gas, typically air, before impinging upon the target surface. Therefore, entrainment of the surrounding fluid can be considered to be negligible so that a potential core is not relevant in this case. Due to the intensive trend of component miniaturization, the available space for the cooling device will likely be very restricted. Different types of jets are showed in Figure 1.

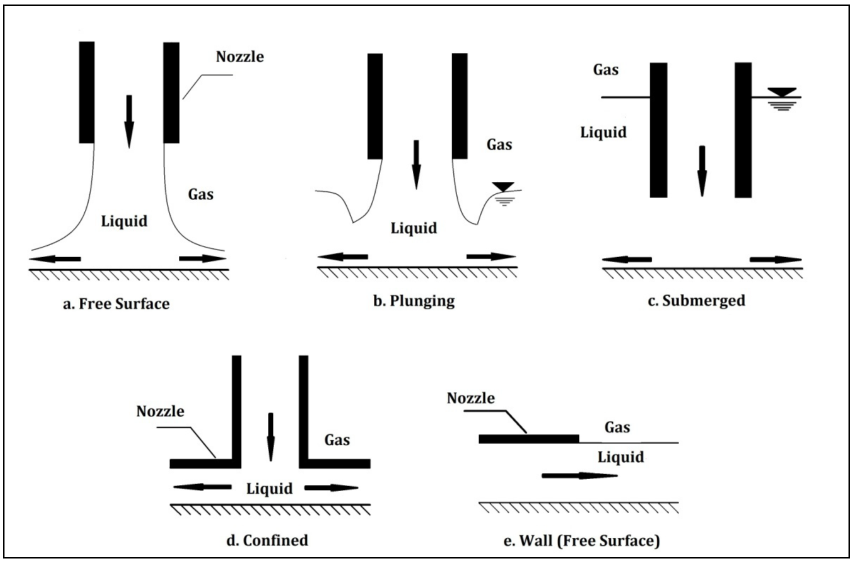

Fig 1: Different Types of Impingement Jets.

The magnitude and distribution of the heat transfer coefficient has been found to be dependent on a number of parameters, including Prandtl number (Pr), Reynolds number (Re), jet-to-target spacing (H/d), jet diameter (d) and the physical geometry of the jets and heater surface[3,4]. Compared to single jet impingement, the heat transfer and flow characteristics of jet arrays have received much less attention in the open literature, although some works exist.

The popularity of impingement jet systems derives from the fact that they possess one of the highest known single phase heat transfer coefficients. A few studies reviewed heat transfer of impingement jets and their applications. In this study, we concentrate on works related to liquid impingement jets and their applications for cooling and heating in recent years. Also we focus on the types of the jets and their effects on the heat transfer coefficient.

2. HYDRODYNAMICS OF LIQUID IMPINGEMENT JETS

Liquid impingement jet characteristics are similar to gas impingement jets with a few differences. When a liquid jet is impinged on a target, three distinct regions are identified. The first zone is the free jet region, which develops instantly at the nozzle exit and remains throughout the impingement process. When an axial free surface jet impinges on a target, the fluid forms a boundary layer, which grows along the target dimensions (for example radius, for a circular disk as target). The second zone is the impingement region, where the interaction between the jet and the heated target produces a strong deceleration of the flow. After this zone, the liquid wets and flows in a direction parallel to the target. The difference between liquid and gas impingement jets is that, when a turbulent liquid jet impinges on a flat target, a spray of droplet breaks off from the liquid layer formed on the target. This splattering of droplets lowers the efficiency of the impingement jet heat transfer cooling process due to the loss of liquid. The laminar jets do not splatter. When the jet turbulence is sufficiently large, these waves sharpen and break into droplets. All observations indicate that the amplitude of the disturbance on the jet governs splattering [5]. It should be noted that the amount of splattering at a given nozzle to target spacing depends principally on the jet Weber number. Also, the surface tension of the liquid plays an important role in splattering [6]. A liquid impingement jet is shown in Figure 2.

When a liquid is first impinged on the hot surface, it remains stagnant in a small impingement region for a certain period of time before covering the entire surface. This time period varies from a fraction of a second to a few minutes, which depends on the experimental conditions. This wetting delay period is described as the residence time, t*, in the present study. The local wall temperature at the stagnation radius at the residence time is represented by T^*_w in this study. Just after the residence time, the wetting front starts moving and consequently the surface temperature drops at a faster rate.

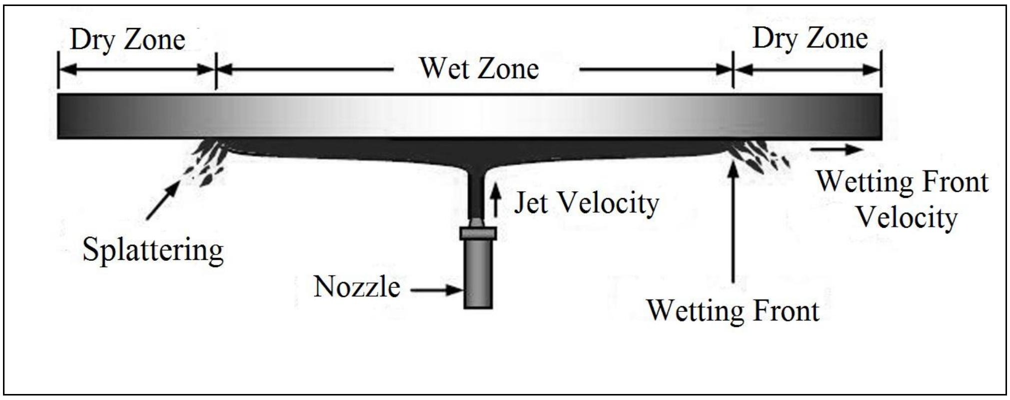

Fig 2: Liquid Impingement Jet.

Before the residence time, the surface temperature drops slowly and almost at a constant rate though there is a sudden drop of temperature at the very beginning of the jet impingement. Some studies also performed on free surface jet impingement cooling; have given valuable background information on single phase convection heat transfer.

3. LIQUID IMPINGEMENT JETS USING NANOFLUIDS

In recent years, breakthroughs in manufacturing processes have permitted the creation of solid particles down to the nanometer scale, which in turn has resulted in the birth of a new and rather special class of fluids, called 'nanofluids'[7,8]. These fluids constitute a very interesting alternative for electronic cooling applications [9]. The term 'nanofluids' usually refers to a mixture composed of a saturated liquid with extremely fine nanoparticles in suspension. Many experimental studies revealed that these innovative working fluids have an extremely high enhancement in thermal conductivity, convective heat transfer coefficient and CHF in boiling heat transfer [10]. It should be mentioned that there is a clear lack of data regarding nanofluid behavior in real thermal applications and some other important issues like the unknown long term effects due to the temperature on the stability and suspension of these special mixtures. In recent years, a few studies on impingement jets using nanofluids have been performed. We believe that a combined system including impingement jets and nanofluids can remove the large amount of heat generated by surfaces in industrial applications such as high performance microelectronic chips.

Yimin and Li [11] in their work presented a procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and a base liquid. By means of the procedure, some sample nanofluids are prepared. A theoretical model is proposed to describe heat transfer performance of the nanofluid owing in a tube, with accounting for dispersion of solid particles. The results show that the nanofluids show great potential in enhancing the heat transfer process. One reason is that the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofluid. Shekhar and Nishino [12] has studied the Upward, laminar, axis symmetric, pipe-issued, submerged impinging jets, with the water as the working fluid, are numerically investigated. When the H/D of the flow was reduced, the jet impinged onto the impingement surface with a larger velocity (due to the pre impingement jet's smaller viscous diffusion), which increased the heat transfer coefficient and the skin-friction coefficient in the forced-convection region, but the local temperature remained almost constant. In the dead zone, on the other hand, the flow properties were affected by both the wall-jet momentum and the degree of interaction between the separated flow and the base surface. When the interaction was weak, the heat transfer coefficient and the skin friction coefficient both increased with the increased impingement velocity, whereas the surface temperature decreased.

Ishigai S. [13] studied experimentally the flow and heat transfer of an impinging round jet over a horizontal plate. They compared their experimental measurements of the film thickness with the theoretical predictions of Watson [14]. There was a good agreement between the two solutions near the center of the jet, but as the radial location increases, the difference becomes wider. Zhao and Masuoka [15] have investigated flow and heat transfer due to liquid jet impingement on a circular surface. They have studied the heat transfer between small jets of 0.9 and 2 mm and a disk of 10 mm diameter. Baonga et al. [16] investigated liquid film, hydraulic jump and local heat transfer distributions along the radial direction of a circular disk. For jet Reynolds number in the range of 1,050 to 9,000, and for each nozzle diameter, the difference between the stagnation and average Nusselt numbers decreases significantly for higher Reynolds number. When the jet Reynolds number increases, the average heat transfer coefficient increases because of the increase in the liquid flow rate. Furthermore, Teamah and Farahat [17] have investigated both the heat transfer and fluid flow due to the impingement of vertical circular water jet on a horizontal heated surface numerically and experimentally. However, the hot surface used in their experiment was square of 0.95 m side. There are few models available for the average liquid jet impingement Nusselt number along circular disks; such models are those given by [15] and [17]. Integral analysis method was used by [15] to solve the flow along the radial direction of the circular disk.

NGUYEN et al. [18] in this paper have experimentally studied the heat transfer enhancement provided by the 5% particle volume fraction Al2O3-water nanofluid, under the configuration of an evacuated impinging jet system. Results have also shown that for the range of parameters studied, the surface heat transfer coefficient seems to do not change much with respect to the nozzle-to-surface distance.

Hosseinalipour et al. [19] in this study, the problem of laminar impinging jet flows of nanofluids has been numerically investigated. Results, as obtained for water-Al_2O_3 mixture, show an enhancement of heat transfer rate due to the presence of nanoparticles in the base fluid. However, inclusion of particles in the flow increases shear stress and pressure drop.

Paisarn and Somchai [20], in this paper, the jet liquid impingement heat transfer characteristics in the mini-rectangular fin heat sink for the central processing unit of a personal computer are experimentally investigated. The experiments are tested with three different channel width heat sinks under real operating conditions: no load and full load conditions. It is found that the central processing unit temperatures obtained from the jet liquid impingement cooling system are lower than those from the conventional liquid cooling system; however, the energy consumption also increases. The results of this study are of technological importance for the efficient design of cooling systems of personal computers or electronic devices to enhance cooling performance. It should be noted that for electronic chip cooling by nanofluids impingement jets, the use of an array of jets is important and more interesting because of the desired uniform temperature distribution on electronic chip. However, no study using an array of jets involving nanofluids is available.

4. CONCLUSION

In this study, we concentrated on a liquid impingement jet and its combination with nanofluids. Thorough reviewing important studies, we concluded that, the increase in pressure drop is significant with the presence of nanoparticles. The parameters that affected the Nusselt number in liquid impingement jets are fluid properties, the geometry of jets, jet velocity, Reynolds number, Prandtl number, nozzle to target distance, material properties of the target, porosity of the target, jet sub cooling for boiling phenomena and nozzle diameter. It seems that there is a need for more study of physical properties and the porosity of target and jet to jet interaction before and after impinging. Different arrays of multiple jets should also be investigated for an acceptable optimization between desirability of more jets and the problem of enhancing pressure drop. The few studies on impingement jets with nanofluids that have been performed and their interesting aspects are shown. However, for the acceptance of these promising characteristics the heat transfer community needs more evidences.

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