Review: Experimental and CFD Analysis on Jet Impingement Cooling of Different Material and Structure

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***Abstract*— This study presents the review on Experimental and Numerical analysis on Jet Impingement cooling. As per the research done by many researchers, jet impingement is highly effective convective heat transfer technology and improving heat transfer enhancement in various applications. Water and Air is used as the test fluid mostly. The Reynolds number is defined based on the various nozzle diameters, Effect of distance between the nozzle exit and target surface, volumetric effect, two phase fluid. Geometries and results part being mentioned starting from simple to complex elucidate cases of a free rotating disk, a single disk in the cross flow, single jets impinging onto stationary and rotating disk as well as multiple jets. Paper focuses on Nusselt number distribution on target surfaces. Reynolds number independent on nozzle diameter, nozzle exit and target surface (h/d) increases when stagnation point Nusselt number decreases monotonically. The effect of Reynolds number and nozzle to plate spacing on the flow structure are examine and the analysis is done with the help of ANSYS FLUENT and some studies validated with the help of previous researches data.**

I. INTRODUCTION

Jet impingement cooling is one of the most efficient solutions of cooling hot objects in industrial processes as it produces a very high heat transfer rate through forced convection. Since the heat transfer rate is very high at the area where the jet directly impinges on it provides rapid cooling or heating on the local heat transfer area. Jet impingement is widely used for cooling, heating and drying in several industrial applications due to their high heat removal rates with low pressure drops.

Fig1: Jet Impingement

Many researches study on the varying nozzle diameters and specimen structures. Most of the works are available on flat plate [1]. Jet impingement heat transfer is extensively used for cooling electronic components, cooling critical machinery structures, annealing metal plates, and numerous industrial processes and also include turbine blade cooling paper and fabric drying , furnace heating, tempering of glass and metal sheets, electronic chip cooling, food processing and many others[2].

In order to achieve a suitable device design, from both economic and technical point view, detailed knowledge of the dependence of the heat transfer rates on the involved parameters is required. Thus, interest in the reported topic, from the stand point of both empirical and theoretical assessments, continues persistent even in recent years [3].

The majority of prior research on impinging gas jets has focused on nozzle-plate spacing much larger than one diameter. No previous quantitative work for z/d < 0.5 in the high Reynolds number, turbulent flow regime has been conducted. The intent of this research is to fill the void in the current impingement literature and to present a qualitative and quantitative understanding of impingement heat transfer and flow structure at low nozzle-plate spacing[4].

Besides, the investigation tools, either experimental or numerical, have undergone tremendous developments which allow for a deeper understanding of the concerned phenomena. Jet impingement technology is used for cooling of turbine blades, annealing process due to diverse range of uses, there have been many investigation on the heat transfer characteristics of impinging jets in the past decades [5].

Several researchers have observed heat transfer enhancement resulting from the addition of a gas (or vapor) phase to an impinging liquid jet. Investigate nozzle diameter effect on heat transfer characteristic of the impinging jet and show that heat transfer of the air-assisted jets was enhanced by a factor of 2.6[6].

In latest years there has been substantial increase in chip level heat fluxes, along with increasing demand for contraction. Design engineers are always looking for better method for stuffing high-power dissipating electronic equipments .As the power dissipation continue to increase, standard conduction and forced-air convection techniques no longer provide enough cooling for difficult electronic systems [7] Heat sink, heat sink with fan, heat exchanger, heat pipes these are traditional methods and have low heat removal rate so instead of these effective heat removal method is jet impingement. The free surface appears immediately at the nozzle exit and maintains throughout the flow regime, including the wall-jet regions. The shape of the free-surface jet is decided by many factors, including gravitational, surface tension, and pressure forces and it is constructed by adopting kinematic conditions, as well as a balance between normal and shear forces at the fluid–gas interface [8].

II. RESULTS AND DISCUSSION

D. Singh et al.[9]carried out the experiment on circular cylinder with fix range of Reynolds no 10,000 to 25,000, h/d 4 to 16 and d/D 0.11 to 0.25 and consist of three numerical models like RNG k-ε, Realizable k-ε and SST k-ε turbulence model. So it concluded that RNG k-ε model perform better than other two turbulent models. Reynolds number of jet increases, the heat transfer rate also increases. The effect of h/d is significant up to 90^0 from the stagnation point in the circumferential direction. The hydraulic jump radius increased with decreasing nozzle diameter and because of Reynolds number condition increase in the impingement power.

Kyo sung Choo et al. [10] investigate that influence of the nozzle diameter on the circular plate, it consist of seven circular stainless steel nozzles they are in straight tube. Compare the empirical correlation of Stevens and Webb as a validation process and result agrees within ±20%.when compare this data it gives hydraulic jump radius increases as the nozzle diameter decreases at fixed jet Reynolds number and also gives the jump radius was independent on nozzle diameters under fixed impingement power condition and whenever hydraulic jump radius increases that time nozzle diameter decreases. Fig2. The dimensionless hydraulic jump radius is governed by the $d^{-1/4}$term when the jet Reynolds numbers is fixed. In other words, the hydraulic jump radius is proportional to $d^{3/4}$ at the fixed jet Reynolds number condition.

Equation2 Shows the dimensionless jump radius should depend on two dimensionless groups.

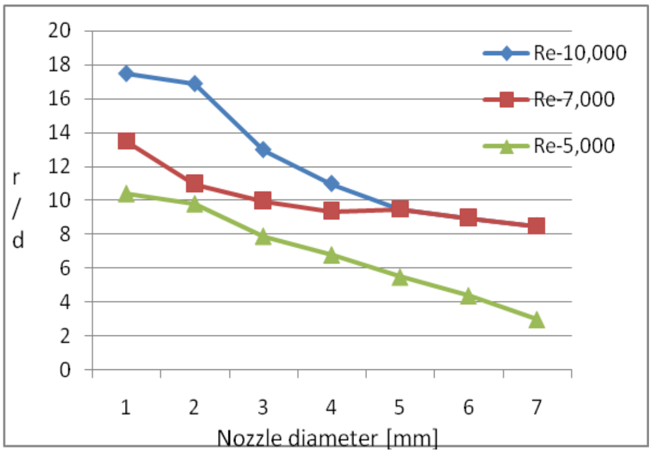

Fig.2. Variation of the dimensionless hydraulic jump radius as a function of the nozzle diameter.

$$R_{hj}/d = 0.037(\pi/8)^{1/4}(Re)^{3/4}(v^2/g)^{1/2}(1/d)^{1/4} \ldots\ldots\ldots(1)$$

$$R_{hj}/d = 0.037(\pi/8)^{1/4}(Re^7Fr^2)^{1/12}(v^2/g)^{1/2}(1/d)^{1/4} \ldots\ldots(2)$$

M. Johson et al. [11] Many studies are available on smooth surfaces but investigated the jet impingement on micro scale patterned surfaces exhibiting ribs and cavities tested in both wetted cavity regions called hydrophilic and unwetted cavity regions called superhydrophobic. First Watson tested above surfaces with wetted cavity regions then Cassie baxter tested with unwetted cavity regions, so these two combine states are study by Test surfaces are fabricated from silicon wafers 101.6mm in diameter using standard photolithographic processes. Since silicon is originally hydrophilic, uncoated patterned surfaces were in the wenzel state. In cassie baxter state the silicon surfaces were coated with a thin layer of chromium for adhesion purposes and then Teflon. When jet impinging cavity, rib structure the shape the hydraulic jump is elliptical with the major axis aligned parallel to the rib and cavity structures. Cavity regions does not wet between the ribs compared to the state where the cavities are wetted. So the eccentricity of the elliptical hydraulic jump increases with increasing Reynolds number. The total area of the supercritical thin film region internal to the hydraulic jump is smaller for patterned surfaces when water wets the cavity regions compare to the non wetting scenario. This is due to increased friction transverse to the rib cavity structures when the cavity is wetted and a decreased friction along the direction of the ribs when the cavity is not wet. The hydraulic jump radius increases in the direction along the ribs and decreases in the direction perpendicular to the ribs. Total supercritical thin film area increases with increasing Reynolds number and decreasing downstream water depth.

Kyo sung et al. [12]experiment carried on balsawood flat plate which is 50*20 mm^2 and 0.8mm thick have low thermal conductivity. Also consist of gold film Intrex, calibrated E-type thermocouples and 4mm diameter of circular nozzle. For insulation used Styrofoam plate 60*60*40 mm^3 was placed behind the balsawood plate to minimize heat losses.

$$Nu = 0.726Re^{0.53}(H/d)^{0.191} \ldots\ldots\ldots\ldots\ldots(3)$$

Using empirical correlation (3) Lytle and webb examine the present experimental data. Gives favorable result of the comparison H/d=6, maximum Nusselt number occurred at the stagnation point and decrease monotonically. The local Nusselt number increased with increasing lateral distance from the stagnation point to the secondary peak and decreased monotonically beyond the secondary peak.

figure3 shows Pressure drop increases under fixed flow rate condition, increases the pumping power and figure 4 shows supplied pumping power does not change although the nozzle to plate spacing decreases. So in order to maintain the fixed pumping power, the flow rate should be decreased while increasing the pressure drop when the nozzle to plate spacing decreases.

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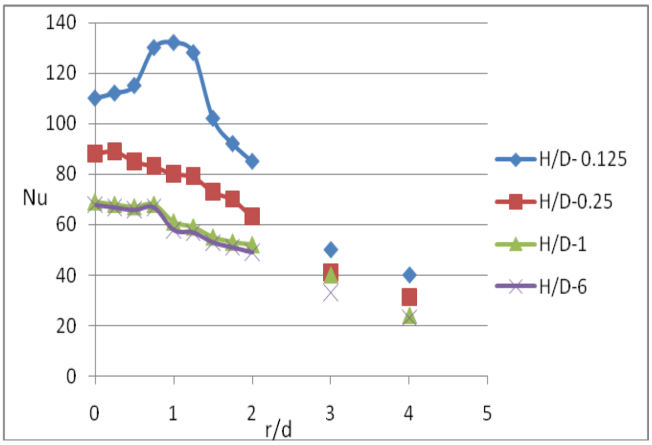

Fig.3. Lateral variation of the local Nusselt number for Re = 5100.

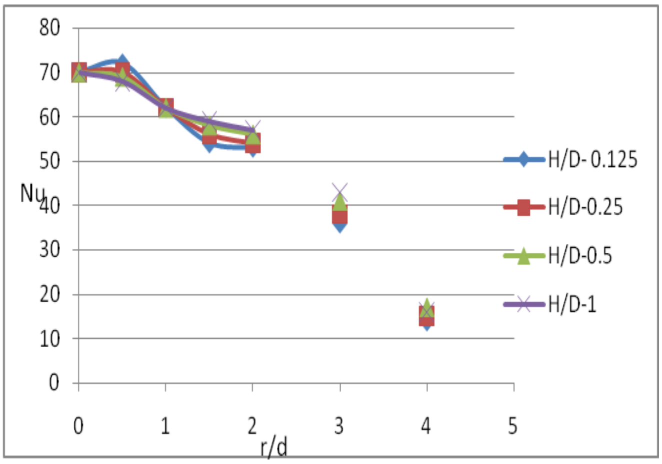

Fig.4. Lateral variation of the local Nusselt number for P_{pump}=3.7*10^{10}

When study was carried out on circular air jet impingement on flat plate it focuses on local Nusselt number. Brian K. Friedrich et al. [13] present study carried on two phase impinging jet And determine the relationship of Nusselt number, Hydraulic jump, and stagnation pressure. Air and water was used as working fluids. Validation for the Nusselt number and stagnation pressure come from the comparison of the single phase liquid impingement data from previous experiments by Webb and Ma and Bernoulies equation gives the result approximate ±10.

$$P_{stag}=1/2\rho u^2+\rho gh\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The effect of volumetric quality on the Nusselt number and pressure were considered under fixed water flow rate condition. The results can be shifting into three regions; Region I is from β= 0 to β = 0.5, Region II is from β = 0.5 to 0.8, Region III is from β = 0.8 to β = 0.9. Region I, stagnation Nusselt number increased linearly as b was increased due to increase in number of bubbles. Region II, the stagnation Nusselt number increased exponentially as b increased, which is in slug flow region. This region also ends at the peak location for the stagnation Nusselt number. Region III starts at the peak location for the stagnation Nusselt number which then rapidly decreases until β = 0.9 is reached due to distortion of jet column.

In addition, it was found that the stagnation Nusselt number of two phase impinging jet is governed by the stagnation pressure and the lateral variation of Nusselt number is governed by hydraulic jump radius. Based on the experimental results, a new correlation for the normalized Nusselt number of the impinging jet is developed as a function of the normalized stagnation pressure alone.

$$Nu^*_{stag}= 0.85P^*_{stag}\ldots\ldots\ldots\ldots\ldots(5)$$

Hang Wang et al.[14] A hydraulic jump is characterized by intense turbulent flow patterns and substantial flow aeration. The flow turbulence, at both macroscopic and microscopic scales, interacts with the air entrainment process and the free-surface. A series of simultaneous measurements of the free-surface fluctuations, jump toe oscillations, void fraction and total pressure variations allowed for an investigation of the interactions between these characteristics. Experiments were conducted for a range of Froude numbers from 3.8 to 8.5. The total pressure measurements were justified for the air-water flow characterization of the flow region with a positive time-averaged velocity. The interactions between roller surface deformation, air entrainment and diffusion, velocity variation, flow bulking, and the associated total pressure field modulation highlighted different flow regions, hence flow patterns, in the roller. The jump toe oscillation was found closely linked to the air entrapment at the toe and velocity variation in the shear flow. The instable total pressure distribution was primarily associated with the free-surface fluctuation for the bubbly roller region and with the velocity re-distribution for the lower shear region underneath. The present work provides new information on the physical characteristics of hydraulic jumps and a comprehensive insight into the nature of such complex turbulent two-phase flow.

Qiang Guo et al. [15] When air jet started that time local Nusselt number increases rapidly and in case when air jet impingement continues to cool down then Nusselt number slows down and study also conclude that RNG k-ε turbulent model is better than other like Realizable k-ε and SST k-ε.

N. K. Chougule et al. [16] Comparison study on single jet impingement and multi jet impingement shows result like multi jet impingement most effective method for cooling than single jet because of high saturated convective heat transfer coefficient in the core region of the jet and multi stagnation points.

Lersak Nakharintr et al. [17] work presented on the magnetic fields effect on the heat transfer characteristics and pressure drop in a confined single jet impingement of mini-rectangular heat sink. Compared with or without magnetic field it is found that Nusselt number increase with increasing the magnetic field strength than without magnetic field effect and there was no significant effect on the pressure drop across the test section. The circular nozzle had an inner diameter of 6 mm, distance between the nozzle exit and the target plate is varied from 4 to 8, the Reynolds number is defined based on the nozzle diameter varied from 14,000 to53,000. when the air jet began its impingement local Nusselt number rapidly increases.

III. SUMMERY

Heat transfer enhancement is the most important topic, now days many researches are available on heat transfer enhancement among them jet impingement is introduced. Thus, it is potentially useful for advanced cooling of materials. This paper presents an overview of the recent developments in the study of jet impingement cooling. The study performance of jet impingement critically shows that when Reynolds number increases with increasing jet impingement on surface, and also overview about Nusselt number indicate that Nu increases with fluid jet and slow down with cooling performance. In numerical analysis RNG k-ε turbulent model is gives better performance.

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