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Enhancement of Heat Transfer with TiO2-Water Nanofluid Jet Impingement: A Critical Review

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Abstract - *Jet impingement cooling is a well-researched method used to achieve high heat transfer rates, with applications in areas like electronics cooling, turbine blades, and nuclear reactors. The addition of nanofluids, especially TiO_2-water nanofluids, has proven to significantly improve heat transfer efficiency by enhancing convective heat transfer and promoting better thermal conductivity. This review investigates the performance of nanofluids of TiO_2 and water in cooling systems that use jet impingement., considering the main factors that influence heat transfer. It also examines the latest advancements in research and discusses the potential future developments in this area. The analysis highlights the importance of parameters such as nanoparticle concentration, flow conditions, and surface characteristics in optimizing the advantages of heat transfer in nanofluids. It also describes the obstacles and possibilities for additional refinement and incorporation of TiO_2-water nanofluids into useful jet impingement cooling applications.*

Key Words: Nano fluid, Heat Transfer, TiO_2-water nanofluids

1.INTRODUCTION

Within thermal engineering, heat transfer is a crucial field that focusses on the production, use, transformation, and interchange of thermal energy, or heat, between various systems. It is divided into a number of mechanisms, such as radiation, convection, thermal conduction, and energy transfer during phase transitions. Energy conservation, material sustainability, thermal regulation, and system compactness all depend on effective heat transport. The need for more efficient heat exchange systems has grown due to technological advancements and the optimisation of industrial processes. Microelectronics, power electronics, nuclear energy, air conditioning, transportation, aerospace, renewable energy, chemical engineering, and other industrial processes are just a few of the many industries that use heat transfer. Three main strategies are employed to increase heat transfer rates: passive, active, and combination strategies.

By adding inserts or other devices, the passive technique typically modifies the channel's flow geometrically or on the surface. For instance, add fluid additives, coiled tubes, surface tension devices, extended surfaces, displacement augmentation devices, treated surfaces, rough surfaces, swirl flow devices, and additional components. The active approach increases heat transmission by requiring some external power input. Some examples of active methods include fluid vibration, surface vibration, jet impingement, suction or injection, mechanical assistance, and induced pulsation by cams and reciprocating plungers. The enhancement is achieved through utilizing an external power source or activator. The compound method, which includes rough surfaces with twisted tapes, fluid vibration, and a swirl flow device, is a combination of passive and aggressive techniques.

Fluids should have low viscosity, high volumetric heat capacity, and high thermal conductivity for optimal heat transfer performance. They must also be safe, economical, non-corrosive, and environmentally friendly. The fact that energy-efficient heat transfer fluids, which are essential for high-performance cooling, are intrinsically less heat-conductive than conventional coolants like water, oil, and EG, is one of the primary challenges in developing them. The coefficient that quantifies the speed at which heat moves from the heat transfer medium to the heat transfer surface is referred to as the heat transfer coefficient is significantly impacted by the thermal conductivity of conventional coolants, making them inherently poor heat transfer fluids. In recent years, numerous methods have been developed to suspend nanoparticles in these fluids to improve their thermal conductivity, which are liquids with typical diameters less than 100 nm. These liquids are referred to as "nanofluids." In addition to lowering emissions, the greenhouse gas effect, and the potential for global warming, the usage of nanofluid will save energy. The stability of nanofluids, which is correlated with the appropriate dispersion of nanoparticles, determines their performance. Sodium dodecyl sulphate (SDS), a surfactant, is added to a nanofluid to lower surface tension, keep nanoparticles from clumping in a base fluid, and keep the base fluid in which the nanoparticles are suspended stable.

1.1 Nanofluid

Conventional heat transfer fluids such as air, water, lubricating oil, and ethylene glycol have much lower thermal conductivities than metals and metal oxides. In order to improve the special qualities of liquid coolants, this restriction is frequently overcome by adding additives

[2]. Additives are nanoparticles composed of a variety of elements, including metals, semiconductors, carbon nanotubes, oxide ceramics, nitride ceramics, carbide ceramics, and composite materials [1]. A base fluid containing uniformly and steadily dispersed nanoparticles (1–100 nm) makes up a novel kind of heat transfer medium called a nanofluid. Metal or metal oxide are frequently the dispersed nanoparticles, significantly improve the nanofluid's thermal conductivity by raising the conduction and convection coefficients, which permits greater heat transfer [3]. Because so many atoms are occupied on the borders, a higher surface area to volume ratio is found in nanoparticles than micrometer-sized particles, making them extremely stable in suspensions. Nanofluids have improved effective thermal properties because the qualities of nano-sized materials, such as thermal conductivity, are usually several times greater than those of base fluids. Because of their smaller size, the dispersed nanoparticles can act in a suspension like a base fluid molecule, which helps us avoid issues like sedimentation and particle clogging that arise with microparticle suspensions.

1.2 Features of Nanofluid

Greater heat conduction is made possible by the nanoparticles' vast surface area. They are mobile and have the potential to cause micro convection because of their small size. The aforementioned factors are responsible for the unusual rise in the nanofluid's thermal conductivity.

Stability: There is less chance of sedimentation because the particles are smaller and weigh less, solving the sedimentation problem. One of the main disadvantages of suspensions can be addressed with less sedimentation. Decreased likelihood of erosion: Because nanoparticles are so tiny, their impact on a solid wall is minimal. As a result, the materials they come into contact with erode less.

Pumping power reduction: Increasing heat transfer in a conventional fluid by a factor of two requires a tenfold increase in pumping power. Unless the viscosity increases dramatically, a very modest increase in pumping power will be needed in the case of nanofluid [4].

1.3 Types of Nanofluid

Fluids with dispersed nanoscale particles are referred to as "nanofluids". Ethanol, Water, oil, EG and refrigerants can all contain carbon materials (like graphite, carbon nanotubes, and diamond) suspended in them, as well as single elements (like Ag, Fe, and Cu), single element-based oxides (like TiO_2, Al_2O_3. Cu_2O, and CuO), alloys (like Ag-Cu, Fe-Ni, and Cu-Zn), multi-element based oxides (like $ZnFe_2O_4$, $NiFe_2O_4$ and $CuZnFe_4O_4$,), metal based carbides (like ZrC, B4C and SiC), metal based nitrides (like AiN, TiN, and SiN), and carbon based materials (like diamond, carbon-nanotubes, and graphite) blended in refrigerants, ethanol, and water. Two main categories into which they can be separated are single material nanofluid and hybrid nanofluid [5]. Nanofluid of a single material. It is regarded as the standard form of nanofluid, in which a suspension is created using a single kind of nanoparticles and several research methods. Several authors have discovered that these nanofluids outperform their base fluids due to their notably superior thermo-physical properties. hybrid nanofluid. Comprising different types of nanoparticles suspended in a base fluid, hybrid nanofluids are a complex kind of nanofluid.

1.4 Nanofluid Preparation

Not merely solid-liquid mixtures, nanofluids are made by solid particles dispersed at the nanoscale without clumping together in base liquids like ethylene glycol (EG), water, oils, and so on. One-step and two-step approaches are the two techniques utilised to prepare nanofluid. As seen in fig. 1[6], Producing nanoparticles and dispersing them in the base fluid are done in a single step using the one-step method. Low production capacities and leftover reactants from an incomplete chemical reaction in the nanofluid are the method's drawbacks.

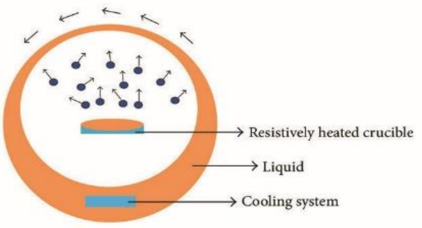

***Figure 1**. One step nanofluid preparation method [6].*

Nanoparticles are created using the two-step technique and then distributed throughout the base fluids. When it comes to producing nanofluid in large quantities, the two-step method is beneficial. There is a drawback to the two-step method while the nanofluid is being prepared, the nanoparticles cluster together without being properly dispersed. Ultrasonic equipment is typically used to decrease clumping and distribute the particles intensely. Other methods, such adjusting the base fluid's pH or adding surface-active agents (surfactants), are employed in addition to the use of ultrasonic waves.

1.5 Jet Impingement

Numerous industrial applications employ jet impingement heat transfer, an active technique that boosts the system's heat transfer efficiency by using external power. An increase in the convective heat transfer coefficient is the result of a high-speed fluid jet that mixes the fluid near the surface and breaks up the boundary layer. When jets hit the corresponding dish, it is known that the area surrounding the stagnation zone has a high heat transfer coefficient.

Single Jet based Impingement

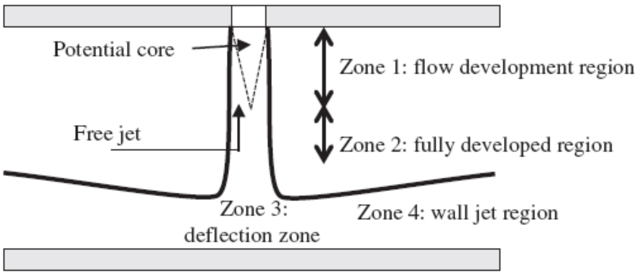

Figure 2 *Arrangement of Single jet based impingement [6].*

1. The flow development region is Zone 1. It consists of a core zone and a free jet zone. The core zone's speed is almost similar as the bulk speed of the nozzle exit. At 95 percent of the nozzle exit speed, the center of the jet's velocity marks the end of the core region. Shear contact with the surrounding fluid causes the free jet zone to enlarge with increasing distance from the nozzle. The rate of flow of the fluid in the free jet area lessens because the surrounding fluid gets incorporated into the jet.

2. At the end of the core is the fully developed area (Zone 2). As one gets farther away from the nozzle, the axial jet velocity drops.

3. The area close to the wall (Zone 3) is distinguished by a steep drop in axial velocity and an increase in static pressure. The deflection zone is the name given to this area. The point of stagnation is located in the center of the deflection zone.

4. After reaching its maximum, the transverse velocity in the wall jet zone (Zone 4) gradually falls. Since the stabilizing influence of the acceleration diminishes, the flow becomes turbulent because of the deceleration. Because of this change from laminar to the turbulent shift in the flow, heat transmission is improved and a resulting peak appears on the Nusselt number change at low separation distance values. Therefore, a number of factors influence the heat transmission coefficient. The most important ones include velocity profiles, heat flux, jet Reynolds number, turbulence intensity, nozzle shape, and nozzle-to-plate distance. According to a key finding of single jet studies, heat transmission is strong at the collision zone but quickly drops away from it. Using numerous jets, as shown below, is one way to get around this issue.

With the aid of the jet impingement cooling technique, numerous heat transfer issues can be resolved by pushing fluid onto a heated surface. The jet impingement cooling method is widely used in many industrial areas, including the production of metal sheets, the drying of textiles, paper, and wood, the cooling of high-temperature glass, and the cooling of internal combustion engine pistons, due to its greater heat and mass transfer rates and ability to thin the boundary layer of the heated surface [7]. Use of nanofluid to accelerate heat transfer is known as the jet impingement technique has drawn the attention of several researchers over the last three decades. In the present day, this kind of technique is widely employed in numerous industrial applications. To date, many researchers have conducted experimental, numerical, and theoretical studies. Their primary goal was to manipulate a number of variables, including the Reynolds number, the distance between the target jet and the plate, the concentration of nanoparticles inside the base fluid, the angle at which the jet is projected, and others, in order to improve the coefficient of heat transfer of the nanofluid. Jizu. Lv et al. [7] carried out an experimental study with nanofluid of SiO2-water for the following parameters: jet to target plate distance 2–5; jet impingement angle 30-90 degrees; Reynolds number 8000–13000; and volume fraction 1-3 percent. They found that the SiO2-water nanofluid with a volume fraction of 3–0 percent nanoparticles had the largest increase in heat transfer coefficients, by 40 percent, when compared to pure water. An Al2O3-water nanofluid with a volume fraction ranging from 0 to 5 to 2 percent was used in the experiment. Jizu Lv et al. [8] found that the nanofluid's convective heat transfer coefficient reduces as the impact angle increases and rises with the volume fraction and Reynolds number. Performance in heat transfer is optimal when H/D=4. For Al2O3-water nanofluids with a volume proportion of 2 and 0 percent nanoparticles impinging vertically, the heat transfer coefficients were 61 and 4 percent higher, respectively, than pure water under Re=12,000 comparison. Using varying particle volume fractions results in a similar tendency for the heat transmission coefficient, which decreases radially. Bin Sun et. al. sconducted a study to assess the heat transfer efficiency of a heat exchanger using an experimental Cu-water nanofluid. They discovered that the optimal heat transfer occurs with a circular nozzle spaced 3 mm from the target plate, and that the heat transfer rises with increasing jet angle. Using an Al2O3-water nanofluid, Jaware V.B. et al. [10] conducted an experiment in which they examined a number of parameters, including the volume fraction between 0.1-0.5%, in terms of nozzle diameter ratio (H/D) and target to plate distance, the ranges are 2 to 18 mm and 2 to 4 lpm, respectively. Maximum heat transfer required an H/D ratio of 2 to 8 and the heat transfer coefficient increased from 24 to 44 percent for volume fractions of 0 to 1 to 5 percent, respectively. The experimental study that Qiang Li et al. [11] conducted, showed that using a copper-water nanofluid for submerged jet impingement improves the heat transfer coefficient. for nanoparticle dimensions of 25 nanometers compared to 100 nanometers. Using an Al2O3-water nanofluid, both experimental and numerical research were carried out by Mohamed A. Teamah et al. [12]. At Reynolds number 24000, they discovered that the heat transfer coefficient rises to 62 percent as both Reynolds number and volume concentration rise. TiO_2 has the lowest heat transfer rate, while CuO has the highest, according to their comparison of the three nanofluids' heat transfer rates (TiO_2, CuO, and Al_2O_3). Santosh K. Nayak et al. [13] evaluated the heat transfer performance using TiO2-water and Al2O3-water nanofluids by incorporating a jet impingement experiment. As the distance between the jet and the target plate increases, the heat transfer coefficient decreases, and it rises to a certain point as the concentration of nanoparticles increases, the results show that Al_2O_3 outperforms TiO_2 and water. For nanoparticle concentration, the maximum heat Nusselt number measured was 2 points 0 percent, and the twisted tape ratio was 6. In an experimental investigation, K. Wongcharee et. al. [14] delved into the characteristics of swirling impingement jets, utilizing a TiO2-water nanofluid as the test substance. D. Lee, H. [15] conducted the study, in order to investigate heat transfer, used the following parameters: twisted tape ratio (Y/W) 4-7, volume fraction 0.5-2.5 percent, Reynolds number 5000-20000, and jet to target space ratio (H/D) 1-4.

2. CONCLUSIONS

Because of their enhanced thermal characteristics and increased turbulence at the target surface, TiO_2-water nanofluids greatly improve heat transfer in jet impingement systems. Improvements in jet system designs and nanofluid synthesis hold the potential of overcoming obstacles like viscosity and stability. It is anticipated that future developments will expand the potential uses of this exciting technology and further optimize performance. A higher Reynolds number, more nanoparticles in the base fluid, and a greater distance between the heated surface and the nozzle all contribute to the nanofluid's convective heat transfer coefficient.

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