**Experimental study of Zn-water nanofluid heat transfer enhancement through an oval twin impingement jet**

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**Abstract.** An oval cross-sectional-area twin jet were studies experimentally studied under constant heat flux conditions to clarify the effect of both Zn-water nanofluid along with such oval twin jet on the thermal characteristic and provide the lack data in such field. The validation was conducted with comparable study and it showed acceptable deviation. The emerged results referred to that the Nusselt number is remarkably increase as the nanoparticle concentration, Reynold number and the distance between nozzles increase. The higher enhancement was found to be 2.1% at high Reynold number value (Re=1000), S/D=5 and nanoparticle concentration ϕ=0.5.

**Keywords:** Nanofluid; Heat transfer; Volume fraction; Twin jet; Nusselt number.

### 1. Introduction

Heat transfer is an essential field and correlated in many aspects of human beings. It effects are noticeable in many fields such as industry, agriculture, health and weather [1]. Improving the heat transfer is that challenge which needs an effort synergy to overcome the encountered difficulties [2-4].

In general, heat transfer enhancement could be passive, active or compound [5, 6]. Impingement jet is one of the prominent application which need further investigation because its wide application in industry [7]. Authors and researchers paid attention to various types of working fluids and jets through the past few years, Li et al.[8] studied the Cu-water nanofluid in a single rounded nozzle. The study conducted with 1≤Z/D≤3. The Reynold number range was 2000≤Re≤10000. The reported outcomes referred to that the heat transfer coefficient is increase as Reynold number. Nguyen et al. [9] tested the performance of Al2O3-water nanofluid in single circular submerged jet under turbulent flow condition 3800≤Re≤8800. The tests carried out at 0.66≤Z/D≤3.33 and 5≤Pr≤10. Tests showed that the nanofluid can enhance the heat transfer in a certain conditions and it performance is adverse in other conditions.

An experimental study was performed by Abdullah et al. [10] at 1 ≤ Z/D ≤ 11 and 1 ≤ S/D ≤ 3. It was found that the maximum gain in heat transfer is achieved at high Reynold number. Singh et al. [11] conducted a series of experiments on a heated cylinder surface at (10000 ≤ Re ≤ 25000) and air as a
working fluid. The test performed at $2 \leq S/D \leq 4$ and $4 \leq Z/D \leq 16$. It was found that the heat transfer is increase as the $S/D$ increase.

The impingement jet application endure from a big gap that concerns the working fluid type, nozzle shape, $Z/D$, $S/D$ and other operational conditions. In the view of such situation, the current experimental tests carried out to fill a portion in this gap representing by adoption Zn-water nanofluid in an oval twin nozzles under laminar flow conditions.

2. Nanofluid preparation

A simple direct method was followed prepare the nanofluid [12-14]. In the current preparation steps, the nanoparticles (Zn 50 nm nanoparticles) were dispersed directly with an agitation device to mix the mixture. Five nanoparticle concentrations were tested in the current study 1%, 2%, 3%, 4% and 5%. The stability examination is achieved by the scan electron microscopy (SEM) as in figure 1.

![Figure 1. SEM image of Zn-water stability.](image)

3. Experimental setup and procedure and data reduction

The experimental rig is depicted in figure 3, it constructed to be consist of pumps, oval cross-sectional area nozzles, square target plate (20×20 cm), heat exchanger, constant temperature tank, valve and measuring instruments. The first pump is the gear pump which circulate the nanofluid into the pipe system and provide the required power to impinge the nanofluid through the nozzles, while the second pump function is to suck the nanofluid from the accumulating vessel and push it to the heat exchanger for heat removal process. Thereafter, the nanofluid is settled down in the main tank at the constant temperature 25°C. The operational Re range was 200-1000, the exact value of the required Re were calculated from the flowing mass flow rate which easily measured by the flow meter, while it controlled by control valve. The tests conducted under constant heat flux 7000 W/m2 conditions that applied to lower surface of the target plate by standard wire gage SWG.

where $I$ is the current and $V$ is the voltage. Ten J-type were fixed at the bottom of the plate to get temperature distribution. The lower surface temperature $T_{ls}$ is directly measured by thermocouples and the upper surface temperatures $T_{us}$ of the plate were measured as follows.

$$q = -k(T_{us} - T_{ls}) \quad (1)$$

The Reynold number, Nusselt number and heat transfer coefficient are calculated as follow

$$Re_{nf} = \frac{\rho_{nf}uD}{\mu_{nf}} \quad (2)$$

$$Nu_{nf} = \frac{hD}{k_{nf}} \quad (3)$$

$$\dot{m}C_p_{nf}(T_o - T_i) = hA(T_{us} - T_i) \quad (4)$$
Where $A$ denotes to the nozzle cross-section area and calculated by $A=\pi ab$. The following figure 2 the experimental rig.

4. Results and discussions

4.1. Validation
The validation was conducted with the study proposed by Sun et al. [15] which embrace single circular nozzle with deionized water as shown in figure 3.
The above validation was conducted under the same conditions and limitations that stated in ref. [15] to fulfil a perfect match and verifying the correctness of the followed procedures, measuring instruments and devices. It shows a maximum deviation of $\approx \pm 4\%$, it is a slightly high value of deviation, but forasmuch as the inherent uncertainty of instrument, the difference in nozzle shape, and different assumptions or approximations. Anyway, the deviation is considered acceptable in view of the mentioned reasons.

4.2. Nusselt number results
The experimental tests were carried out under laminar flow ($Re=200$-$1000$) and constant heat flux conditions. The $Z/D$ was hold to be constant, while the $S/D$ was varied to be 2, 3, 4 and 5. Five nanoparticle concentrations ($\phi=0.1\%$, $0.2\%$, $0.3\%$, $0.4\%$ and $0.5\%$). After running the tests, the temperature distribution was acquired and the Nusselt number is as figure 4 shows below.
The above figure showed a weak enhancement at low value of Reynold number which is considered normal behaviour due to the little amount of nanofluid striking the target plate, which left the plate with warm surface. As the Reynold number increase, the Nusselt number is rapidly increase due to the heat removal process from the target body by the nanofluid and also the collisions between the nanoparticle and plate are helped in prompt the heat exchange, besides the collision between nanoparticles itself. In addition, the Nusselt number is also noted to be increase as the Reynold number increase due to the fact that as the nanoparticle concentration increase, the overall thermal conductivity of the working fluid is increase, which causes an extra heat exchange. On the other hand, the second major parameter S/D was noted to has influence effect on Nusselt number. Where the Nusselt number increase as the S/D increase, this could be came out due to the fact that as the nozzles become far away from each other. Eventually, these figures 4(a, b, c and d) showed acceptable enhancement comparing to plain water working fluid. The lower enhancement was detected to be 0.7% at low Reynold number(Re=200), S/D=2 and nanoparticle concentration $\phi=0.1$. And the higher enhancement was found to be 2.1% at high Reynold number value (Re=1000), S/D=5 and nanoparticle concentration $\phi=0.5$.

5. Conclusions
An oval cross-sectional areas twin jet was tested by using Zn-water nanofluid for Reynold number 200-1000, nanoparticle concentration 0.1-0.5% and S/D range of 2-5, while the Z/D was held constant. The gained outcomes showed acceptable enhancement comparing to plain water working fluid. The lower enhancement was detected to be 0.7% at low Reynold number (Re=200), S/D=2 and nanoparticle concentration φ=0.1%, which reasonable due to low impinging flow rate and low nanoparticle concentration. And the higher enhancement was found to be 2.1% at high Reynold number value (Re=1000), S/D=5 and nanoparticle concentration φ=0.5.

6. Nomenclatures

| Greek Symbols       |                                      |
|---------------------|--------------------------------------|
| A                   | Area of the nozzle exit              |
| A_t                 | The surface area of the target plate |
| C_p                 | Heat capacity                        |
| h                   | Heat Transfer Coefficient            |
| I                   | Electric current                     |
| k                   | Thermal Conductivity                 |
| m'                  | Mass flow rate                       |
| Nu                  | Nusselt Number                       |
| Pr                  | Prandtl Number                       |
| Q                   | Volumetric flow rate                 |
| q                   | Supplied electric power              |
| Re                  | Reynold number                       |
| T                   | Temperature                          |
| t                   | Target plate thickness               |
| u                   | Fluid velocity at nozzle exit        |
| V                   | Voltage                              |
| Z                   | Nozzle-to-target plate distance      |

| Subscripts          |                                      |
|---------------------|--------------------------------------|
| bf                  | Base fluid                           |
| f                   | Fluid                                |
| i                   | Inlet                                |
| ls                  | Lower surface                        |
| nf                  | Nanofluid                            |
| t                   | Total                                |
| us                  | Upper surface                        |

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