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Research paper

Discussion paper: effect of the nanosolution concentration on a heated surface of the heat transfer enhancement using twin impingement jet mechanism

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Abstract

The range of industrial applications with impinging jets is wide for cooling and heating engineering and industrial applications due to its high convective heat transfer coefficients. This study noted the lack in the information of using Nano surface coated aluminium plate on the heat transfer enhancement. There is a clear gap about using Nanosolution coating in the twin impingement jet technique. Furthermore, the interaction between the correlated factors and the correlation relates Nusselt number with the significant parameters have not been investigated before. The main objective of this article is to present the methodology associated with mixing region of twin jets arrangement for flow and heat transfer enhancement. This research will present a study which sought to enhance heat transfer by employing a twin jet impingement mechanism, impact of using Nanocoating on the surface plate and investigating the impact of the distance between the nozzles and plate, Reynolds number and the spacing between nozzles at the horizontal distance from stagnation point on the Nusselt number (Nu). The design of experiments approach (DOE) that employed response surface methodology (RSM) will use to conduct the heat transfer parametric study. This research will use 3 different heat transfer enhancement processes, considered the TiO2 nanosolution coat, aluminium plate heat sink and a twin jet impingement system. The researchers could prepare different nanosolution, which consisted of varying nanoparticle concentrations, and coated them on the metal surface. Thereafter, researchers have to carried out (XRD) and (FESEM) analysis for determining the structure and the homogeneous surface coating of the nanosolution. the results of this study will design the methodology of this research. This technique will achieve the mission to improve the performance of various industrial and engineering applications.

Keywords: *Heat Transfer Enhancement; Twin Impingement Jet; Nanocoating; Design of Experiment (DOE).*

1. Introduction

Much of the research interest has now been conferred to jet impingement heat transfer mechanism [1]–[4]. This article provides a detailed description of the phases and the steps undertaken to augment the heat transfer rate based on the twin impingement jet. The study was undertaken using several types of equipment, instruments, and experimental procedures by [5]–[8]. The definitions of all parameters involved in the twin impingement jet flow and heat transfer investigation and the experimental process were described. The theoretical principles of twin jet flow concepts such as jet velocity, Reynolds number, nozzle-nozzle spacing, nozzle-plate distance, and Nanosolution coating concentration were defined. Next, the impingement heat transfer characteristics such as the Nusselt number and heat transfer enhancement evaluation were described in detail, followed by describing the different flow and heat transfer characteristics along with their respective calculation methods. Heat transfer measurements were conducted using certain heat generation and measuring techniques to address the twin impingement jet performance. This was followed by conducting flow experiments according to certain procedures and considerations to obtain accurate measurements. In summary, the next experimental steps will represent the experimental method undertaken in this study.

2. Methodology

This part supplies a detailed description of the phases and the steps undertaken to enhance the heat transfer rate based on the twin impingement jet as seen in figure 1 that presents the process flow activities and overall sequence of the flowchart of the research activities. Figure 2 presents the experimental and numerical methods analysis phase which discusses the methods by which to evaluate the performance of the Twin impingement jet. The research methodology overview is depicted in this figure. Figure 3 illustrates the flow chart of the experimental procedure and methodology of twin impingement jets tests setup. The twin impingement jet flow and heat transfer study were established by preparing several types of equipment, instruments, and procedures of experiments. The instruments related to jet flow measurements were selected. In addition, heat transfer measurements were carried out using certain heat generation and measuring techniques. Then, the flow experiments were carried out according to certain procedures and considerations that were followed for accurate measurements. Heat transfer experiments were performed to address the twin impingement jet performance.

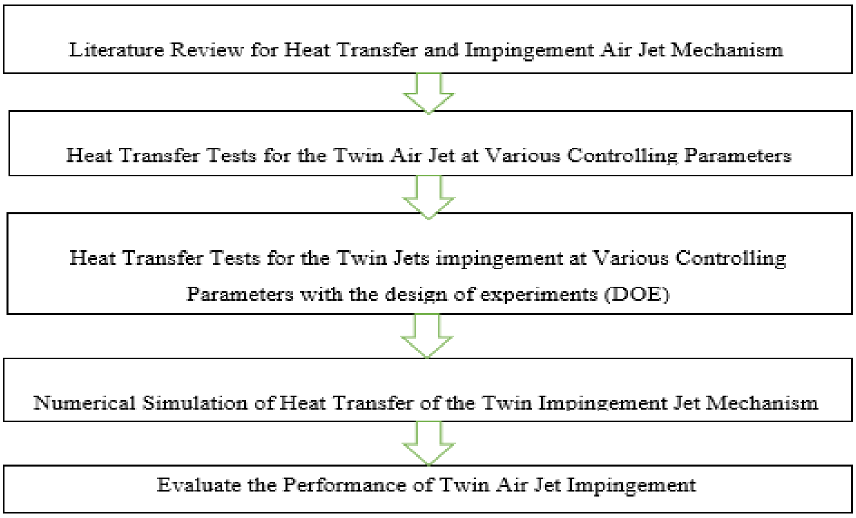

Fig. 1: Overall Sequence of Flow Chart of the Research Activities.

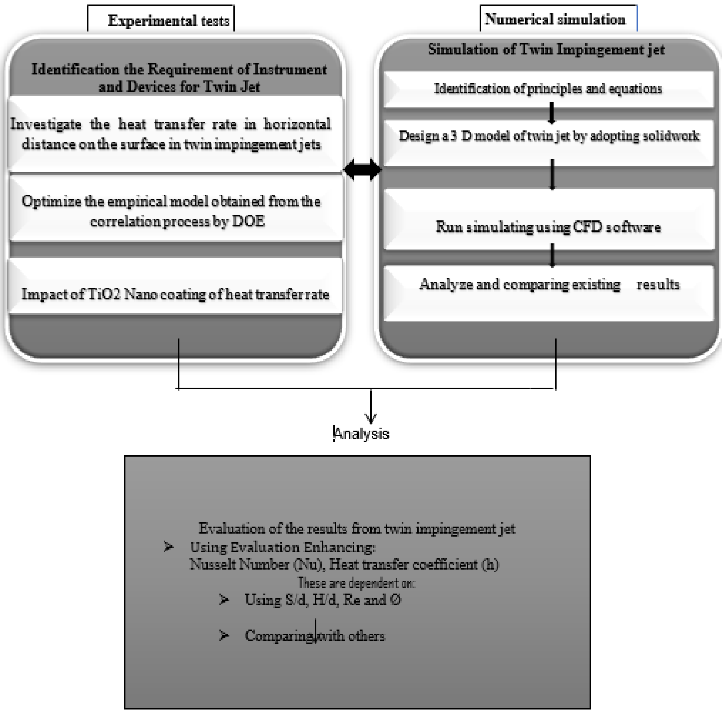

Fig. 2: Research Methodology.

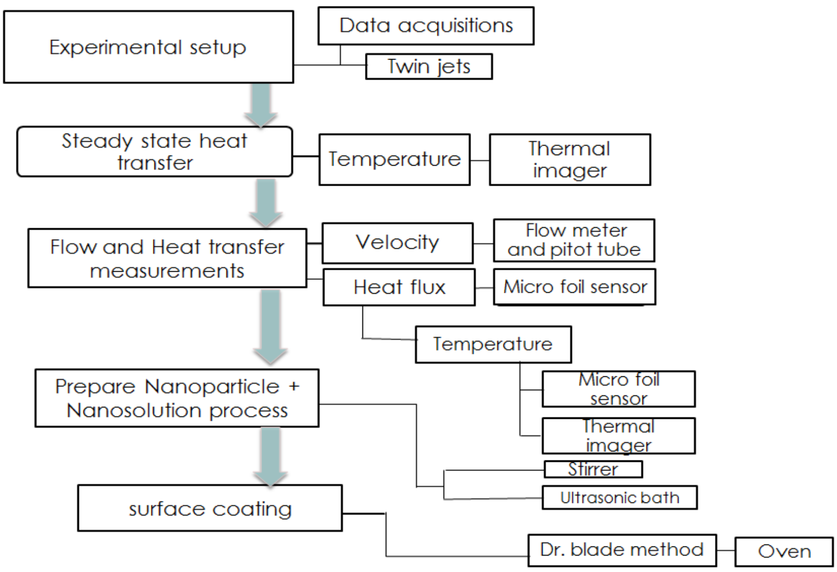

Fig. Error! No text of specified style in document.**:** Flow Chart of the Experimental Procedure and Methodology of Twin Impingement Jets Tests Setup.

As seen in Figure 1 that present the process flow activities and overall sequence of the flowchart of the research activities. Figure 2 presents the experimental and numerical methods analysis phase discusses and the methods by which to evaluate the performance of the Twin impingement jet, the research methodology overview is depicted in this figure. Figure 3 below illustrates the flow chart of the experimental procedure and methodology of twin impingement jets tests setup.

3. Plate coating

3.1. Preparation of the surface coating

Figure 4 shows the schematic diagram of the heat transfer test and the thermal imaging setup. Figure 5 shows the schematic diagram of the heat transfer test with TiO_2 Nanocoating surface plate. The TiO_2 nanoparticles were dispersed in deionised water and ethylene glycol (80:20) at three different concentrations: 0.1%, 0.5% and 1% M. The solution was sonicated continuously for 120 min in an ultrasonic bath under ultrasonic pulses of 100 W at 40 kHz for uniform dispersion of the particles then placing the solution in a hot plate for 15 min at 450 rpm, at room temperature. Moreover, the sonication treatment significantly improved the stability of the suspension. However, it took longer than 120 min after preparation for the TiO_2 nanoparticles to start precipitating. Thus, the TiO_2 nanoparticles remained well dispersed in H_2O and EG before the surface coating. Next, after preparing the nanosolution, the concentration of the nanosolution became (0.2, 1, 2%) by volume. The Doctor-Blade method was used as the coated method [9]. The plate was then placed in the oven for 120 min at 65 ℃ to dry the plate.

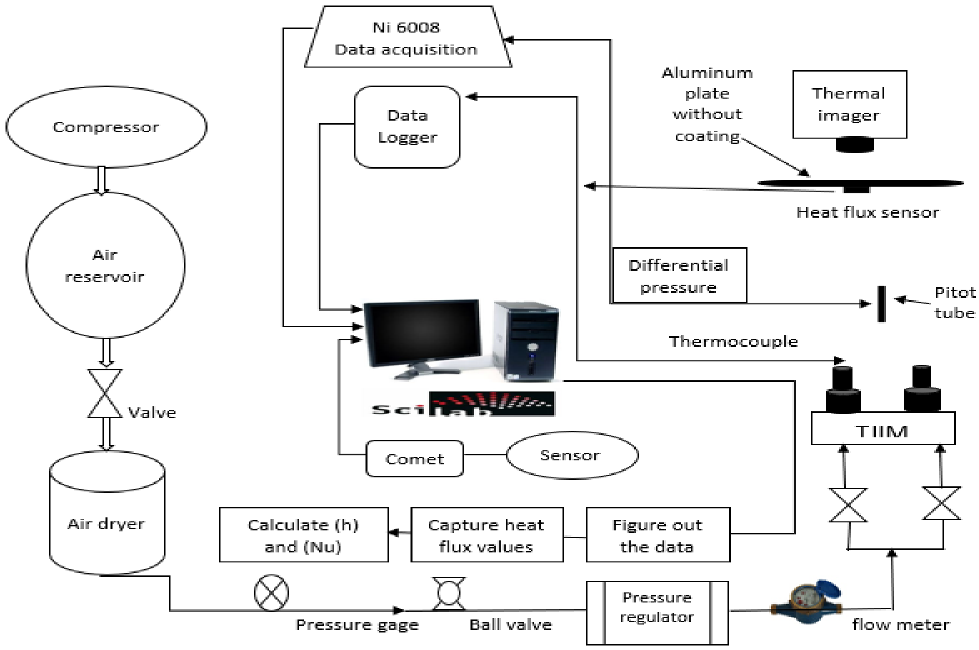

Fig. 4: A Schematic Diagram of the Heat Transfer Test and the Thermal Imaging Setup.

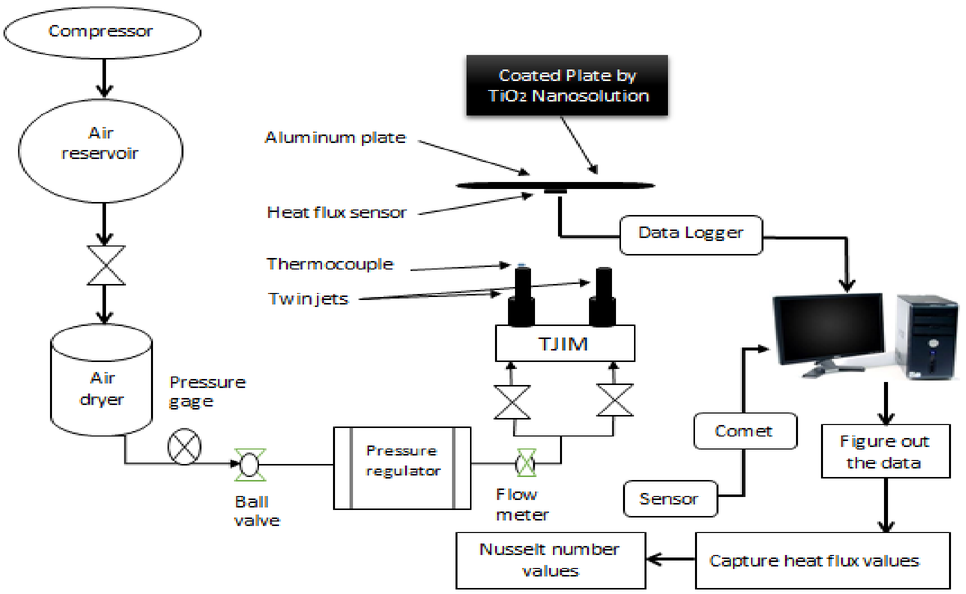

Fig. 5: A Schematic Diagram of the Heat Transfer Test with Tio2 Nanocoating Surface Plate.

3.2. Experimental setup

Figure 4 and 5 provide the schematics illustration showcasing the experimental setup used in this research work. Compressed air of 4 psi (0.275 bar) was supplied through the main compressor. The compressed air is stored in an air reservoir, where a ball valve controls the release. The moisture from the compressed air was then removed with the help of a refrigerated air dryer as mentioned earlier. A pressure gauge and regulator were used to manage the air pressure, which also helped to avoid any unwanted fluctuation due to cyclic on/off of the main compressor. The rated airflow was measured via a digital air flow meter (Model VA 420 procured from CS instruments). The air was made to pass through two identical pipelines before entering the twin jets impingement mechanism. A ball valve ensured control of each of the lines and the twin jets' identical flow properties.

The plate of aluminium was held firmly to ensure a flat surface of impingement. A square piece of aluminium foil having dimensions 30 cm × 30 cm × 0.4 cm as well as a heat flux-temperature foil detector were attached on the front of the aluminium foil with a heat sink compound of high conductivity and a Kapton tape to minimise the impact of the gaps of air between the aluminium surface and the sensor by [3]. The positions of the thermocouples and the heat flux sensor attached on the aluminium plate surface are illustrated in Figure 6. Figure 7 displays the setup of the nozzles for each model (9 cases). For the target of the jet impingement, a square aluminium plate of thickness L and surface dimensions given above was used. [4], [10]

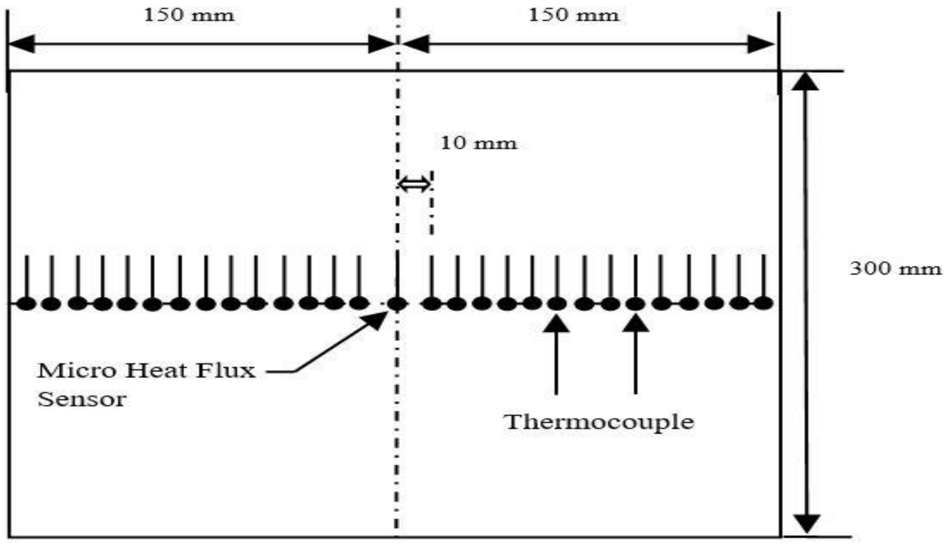

Fig. 6: Locations of the Thermocouples and Heat Flux Sensor on the Flat Impingement Surface.

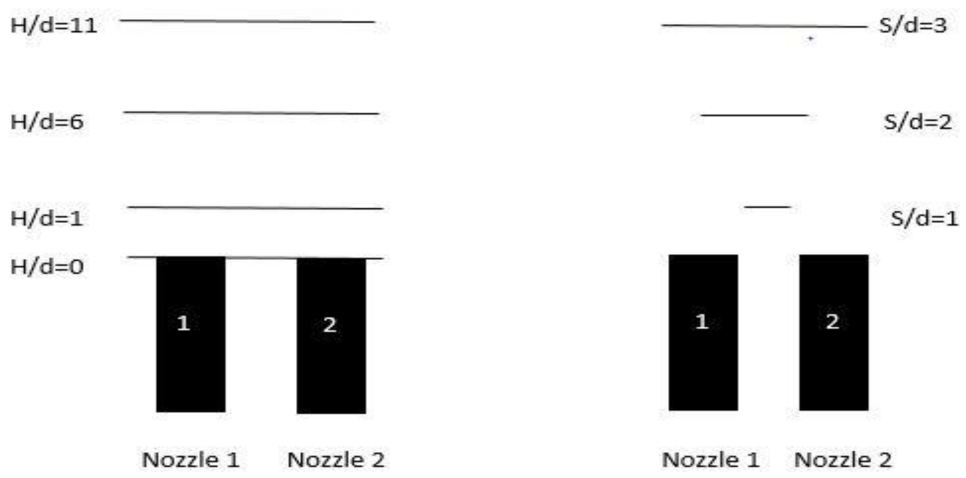

Fig. 7: Arrangement of Nozzles for the 9 Models.

In this research, we utilised K-type thermocouples which were set 120 mm apart and fixed to an aluminium plate to supervise the temperature of the plate. Data from each of the sensors, like temperature, room humidity, static pressure and atmospheric pressure, were gathered by the comet device H7331.

The aluminium foil with small thickness and high heat conductivity (k) ensured uniform distribution of temperature throughout the thickness of the foil for getting accurate readings of the temperature at the surface [11].

3.3. Experimental procedures

The localised Nusselt number was calculated for the 15 points at the horizontal distance from the stagnation point on the measured surface (at the middle of the surface plate). To perform the experimental procedures, the following steps were adopted. First, in the case of the steady jet, the air flow was set by determining the velocity for the twin jets centre point near to the nozzle exit using a Pitot tube to achieve Reynolds numbers of 17,000, 13,000 and 9,000 for every jet [12].

Second, a digital air flow meter was installed in the TJIM to determine the steady jet flow's flow rate and velocity, by keeping a constant temperature of 100 °C. In this experimental setup, Dantec Dynamic's flow meter anemometer was used. Installation of the flow meter was undertaken between the twin impingement jet pipes, which pass through the refrigerated air dryer and twin jets. Next, an experimental run was conducted for the twin impingement jets by using the velocity obtained from the flow meter, and the Pitot tube was used to confirm this velocity. Then, the highest Reynolds number was attained, which permitted successive capturing of the heat transfer per unit time (q) with the help of the data logger and calculating the convective heat transfer coefficient (h), accounting for the units (W/(m²K)).

Third, with the help of differential pressure, the pressure difference was obtained in the form of an analogue, which was used as input for data acquisition Ni 6008. This was followed by transforming the signal and using the developed Scilab code as the value for the results. The differential pressure was set between the Pitot tube and Ni 6008 data acquisition.

Fourth, at a distance of 1, 6 and 11 cm to the measured surface from the nozzle exit; aluminium foil was installed, using a space of 1, 2 and 3 cm between the twin nozzles specifying that nine (9) models had been built for the experimental test. This preparation allowed the measurement of heat flux and surface temperature on the impingement surface. When heat loss due to the impact of natural convection is equivalent to the heat inlet (near the jets, towards the aluminium foil), it achieves a steady heat transfer. Therefore, to reduce the likelihood of experimental error when using a heat flux-temperature sensor (for the measurement), a total of 4,050 samples were taken, in which the average value was considered. Also, for jet impingement heat transfer issues, fluid mechanics and heat transfer need to be considered. Likewise, the associated dimensionless numbers also need to be ascertained, as shown in Figure 8.

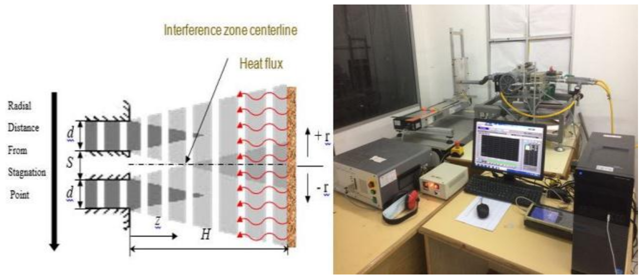

Fig. 8: Twin Impingement Jets Effect and the Original Image of the Setup.

Before the experiments were conducted, several parameters related to the twin jets were kept constant as listed in Table 1.

Table 1: Test Value Parameters

Constant parameter	Value
Nozzle to target distance	1, 6, 11
Nozzle to nozzle distance	1, 2, 3
Reynolds number	17000,13000, 9000
Nano coating solution concentration	0.2, 1, 2 %vol
Ambient temperature	24 °C
Emissivity of foil aluminium	100 °C
Nozzle diameter	2 cm

3.4. Jet flow characteristics

3.4.1. Jet velocity and Reynolds number

The Reynolds number is defined as the ratio of inertial forces to viscous forces that determine fluid flow conditions. The Reynolds number of the twin jets system was determined based on a single jet which delivered half of the air flow rate supplied by the main compressor. Accordingly, the Reynolds number is computed based on the average velocity. The computation of the Reynolds number of the twin air jet, which also correlates with the inertial forces and viscous forces, is given as:

$$\mathrm{Re} = \frac{\rho v d}{\mu}$$
(1)

where μ represents the fluid's dynamic viscosity (Pa·s or kg/(s) or N·s/m^2), ν signifies the fluid velocity (m/s), and ρ denotes the air density (kg/m^3). [13]

3.4.2. Jet impingement heat transfer characteristics

A. Nusselt Number

Forced convection is dominant during jet impingement heat transfer. The Newton's law equation can be employed to determine the heat-transfer coefficient (h), $Q = h(T_s - T_j)$, which gives:

$$h = \frac{q}{T_s - T_j}$$
(2)

Where T_s represents the surface temperature, T_j signifies the air jet temperature and q denotes the amount of heat flux (W/m^2).

The heat flux and surface temperature were measured using a micro foil heat flux-temperature sensor placed on the front surface of the impingement plate, and the jet temperature was measured using a thermocouple located at the compressed air exit. The Nusselt number is evaluated by knowing the thermal conductivity of the air (k) which is determined at the film temperature by [14].

The Nu number equation is used to calculate the ratio of convective to conductive heat transfer as by [13]

$$Nu = \frac{hd}{k}$$
(3)

Where h indicates the convective heat-transfer coefficient, d represents the pipe diameter, and k signifies the fluid's thermal conductivity. [14]

3.5. Doe based on response surface methodology

The parametric experimental study was designed using the DOE approach using response surface methodology (RSM), which also forms part of the current work. This study was designed to correlate the influential factors (Re, H, S and Ø) with that of the heat transfer as well as to present optimum conditions that result in higher heat transfer rates. Design Expert 7 software was employed to design and analyse these experiments. The analysis of variance (ANOVA), a useful technique for statistical deduction, was used in the DOE to study the impact of the input parameters on the experimental observations and to analyse the variation occurring in the measured data. The ANOVA hinges on the assumption that the normal distribution of the errors includes constant variance and mean zero. The user's guide outlines the statistical analysis that is behind this software [15].

In this study, the Nusselt number is the favourable response, which will likely be impacted by the parameters that are under consideration. In RSM, the relation of the desired response that can be impacted by natural input variables can be presented for the current case as [16]–[18]:

$$\mathrm{Nu} = f(\mathrm{Re}, S, H, \theta) + \varepsilon$$
(4)

Where f represents the unknown response function and ϵ denotes the source of noise or error, which has not been accounted for in f. Statistically, ϵ is considered to be distributed normally along with the variance and mean zero [19].

In the present work, the suggestion of the second order polynomial regression, also known as the quadratic model, was used given its ability to predict model parameters and high flexibility apart from its excellent performance as indicated practically [19]. Accordingly, the representation of the response surface is calculated as follows:

$$y(\mathrm{Nu}) = \beta o - \beta_i x_1 - \beta_{ii} x_2 - \beta_{ii}\ x3 + \beta_{ij} x_4$$
(5)

Where β_0 represents a constant and β_i, β_{ii} and β_{ij} denote the coefficients of linear, quadratic and interaction terms pertaining to the second-order model, respectively. RSM is aimed at determining such polynomial coefficients that provide optimal response surface (y). The 'x's signify the coded variables that correspond to the actual parameters that are being considered. Here, x_1 , x_2 x_3 and x_4 denote the coded representation for the Re, S, H and Ø parameters, respectively. ΔRe, ΔS, ΔH and ΔØ indicate the differences of the considered parameters between the higher and lower values. Under RSM, various experimental designs can be classified based on their use for optimisation purpose. However, the most commonly applicable ones are the face cantered cube design (FCD), central composite design (CCD) and D-optimal design [20].

In particular, CCD employs extra levels for the specified range of factors that are under consideration to attain the property of rotatability [17]. In fact, physically, this condition cannot be applied for the case study due to the restriction of limited factor levels like in the case of Nano concentration, in which there is no level higher than its maximum limit, and less than its lower limit as a result of this factor's periodic behaviour.

However, several of the factors offer greater flexibility with regards to modifying their levels but continue to face the physical constraint associated with the experimental setup, which makes the FCD's cuboidal region feature unsuitable for the case under investigation [16]. Moreover, this work specifies that 50 runs [each] are generated by FCD and CCD, whereas, the D-optimal algorithm achieved the goal of the current experimental work in just 25 runs. The attractive feature of the D-optimal design is that it increases the accuracy of the estimated polynomial coefficients (β's), while the maximum variance is minimised as a result of the maximisation of the determinant for the matrix in which $|X^T X|$ is the design matrix [20]. Consequently, the adoption of the D-optimal design is undertaken to configure an optimum relation between the influential parameters and the response since it is considered as the preferable selection for approximating the surface response [21].

In general, the experimental data were required to construct the DOE models based on a specific experimental design. In this study, a combination of the D-optimal design was undertaken with two levels of factors (low of -1 and high of +1) along with a minimum of 21 model points, four (4) replicates and four (4) points to determine the lack of fit, such that the total number of experiments was 25. The feasible ranges of the identified parameters are shown in Table 2.

Table 2: The Experimental Ranges and Levels of the Considered Parameters

Parameters	Ranges and levels -1 0 +1	Units

Reynolds number (Re) 9000 13000 17000 -
Dimensionless nozzle to nozzle spacing (S/D) 1 2 3 -
Dimensionless nozzle to plate distance (H/D) 1 6 11 -
Nanosolution concentration (Ø) 0.2% 1% 2% vol

3.5.1. DOE for twin impingement jets heat transfer correlation

For the twin impingement jet, investigation of the heat transfer experiments using the DOE technique was conducted in order to evaluate the improvement of heat transfer and a comparison study for the cases based on the twin impingement jet was also required. The DOE technique aims at establishing the correlation between the four (4) factors that were mentioned above and the Nusselt number as well as to optimise the correlation. These experiments were performed to define the experimental steps relating to heat transfer enhancement which included the following considerations:

1) The experiments were designed based on the DOE software (Design-Expert 7) along with RSM.
2) The software was fed with both low and high levels of each parameter, which added a midlevel in order to make each factor as three levels as described in the previous section.
3) A specific design (plan) of 25 experiments was suggested by the DOE software to obtain the corresponding Nusselt number from these experiments.
4) The suggestion of a quadratic polynomial model was made, and the DOE software was employed to perform analysis of variants (ANOVA), a statistical analysis based on minimising errors, in order to build the empirical model (the correlation).
5) RSM could conduct the model optimisation, which could be achieved by employing the DOE software to set the response (Nusselt number) as a maximum.
6) As shown in Figure 4 and 5, the arrangement of the experimental setup was undertaken which provided a schematic representation, in which fixing of the impingement plate on the traverse system was done in front of a twin jet.
7) On the plate at the midpoint of nozzle-nozzle spacing, fixing of the micro heat flux-temperature sensor was undertaken.
8) At the jet breathing exit, the thermocouple was fixed for measuring the temperature of the air jet.
9) The air jet thermocouple and microsensor were linked to the multi-channel data logger, which remained connected to the computer that recorded the heat transfer data (i.e. heat flux, surface temperature, and air jet temperature).
10) Switching of the plate heater was carried out, in which the temperature was set at 100 ºC.
11) Based on centre jet velocity, measurement of the Reynolds number was done using a flow meter and Pitot tube.
12) A digital calliper was employed to set the nozzle-nozzle spacing at S/D = 1, 2, 3.
13) As illustrated in Figures 4, 5, and 6, the impingement surface was fixed at H/D = 1, 6, 11 between the plate and nozzles.
14) The traverse system was moved to set the nozzle-plate distance, which employed the MiniCTA software to carry the impingement plate to the desired distance.
15) The parameters were reset based on the design suggested by the DOE software and measurements were repeated.
16) The adjustment of the plate was made in which placing of the microsensor was carried out at the midpoint of nozzle-nozzle spacing.
17) The aluminium plate was coated with the Nanosolution at three concentrations (0.2%, 1% and 2%) M.
18) With the help of the multichannel data logger software, the heat transfer data acquiring process commenced with 3,000 samples per measurement point at a sampling frequency of 10 sample/s.
19) Adjustment of the plate was made, in which the microsensor was placed at the midpoint of the nozzle-nozzle spacing.
20) The setting of the Reynolds number was carried out with regards to the centre velocity as determined by the Pitot tube near the jet exit and using a flow meter sensor for confirming the velocity.

3.5.2. Experiments of heat transfer enhancement

Heat transfer experiments using the DOE technique were investigated for the twin impingement jet to examine the enhancement of heat transfer. Although, a comparison study between the cases needs to be conducted based on the twin impingement jet. The DOE technique aims to obtain the correlation between the Nusselt number and the four (4) factors as mentioned previously to optimise the correlation.

The experiments in this study were carried out next as described:

1) The same experimental setup arrangement depicted in Figure 4 and Figure 5 was followed for these experiments.
2) The impingement plate shown in Figures 6 and 8 was located in front of the twin jets.
3) The plate heater was switched on and set at 100 ºC. Type equation here..
4) The nozzle-nozzle spacing was set at S/D = 1, 2 and 3.
5) The plate was adjusted where the microsensor was located at the midpoint of the nozzle-nozzle spacing.
6) The impingement surface as shown in Figure 4 and 5 was fixed at H/D = 1, 6 and 11 between the nozzles and the plate.
7) The Nanosolution coated the Aluminium plate in
8) three different concentrations (0.2, 1 and 2%) M.

9) Multichannel data logger software was utilised to collect the heat transfer data with 3,000 samples per measurement point and a sampling frequency of 10 sample/s.
10) The plate was adjusted where the microsensor was located at the midpoint of the nozzle-nozzle spacing.
11) The Reynolds number was set based on centre velocity measured by the Pitot tube at the jet exit and using a flow meter sensor to verify the velocity of the Pitot tube.

4. Conclusions

The experimental method of heat transfer characteristics related to twin jets impingement was described in this study along with defining all the parameters and analysis techniques that were applied. Furthermore, heat transfer measurements were prepared and calibrated followed by explaining the twin jet flow characteristics. The Reynolds number, the spacing between the nozzles, the distance between the nozzle and plate, and the impact of the Nano solution concentration were next discussed in detail. Accordingly, the heat transfer enhancement factors were defined in order to show the performance of the twin jet. The main objective of this article was presented the methodology associated with mixing region of twin jets arrangement for flow and heat transfer enhancement. Furthermore, the basic theory of the DOE technique for the parametric study purpose was described along with the preparation of the Nanoparticle and Nanosolution. Finally, experimental work could not have been achieved without theoretical fundamentals.

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