



## **3D Numerical Study on Prediction of Turbulent Heat Transfer in Horizontal Impinging Jet**

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### **Abstract**

In the age of technology, it is vital to cool the different parts of a device to use it more beneficially. One of the newest methods is the "Impinging Jet" on a surface which has shown very effective results. Cooling a hot surface with constant temperature with circular, rectangular and triangular nozzles with the same hydraulic diameter is discussed in this paper. In this context, the results of a two-dimensional simulation are compared with experimental data and the effects of different nozzle shapes are studied. V2F turbulence model had the best prediction for Nusselt number, however,  $k-\varepsilon$ ,  $k-w$  Realizable and RSM models over predicted the heat transfer rate in compare with the experimental data. In addition, the three dimensional impinging normal jet with stated nozzle shapes is studied with V2F model and discussed for Nusselt number per geometry. This method can be discussed by adding swirl to the jet to rise the heat transfer rate in the future studies.

**Keywords:** Impinging Jet, V2F,  $k-\varepsilon$ ,  $k-w$  and Nusselt.

### **1. Introduction**

Heating and cooling with impinging jet is very common to solve engineering and industrial problems in heat transfer field. The applications of this method are drying papers and clothes, cooling metals and glasses, plastic formation, cooling turbines blades, etc. in order to cool or

heat a device, using impinging jet is very attractive and inexpensive method, besides it can be used in wide range of heat and mass transfer problems, so scientists have focused on this method [1-2]. Some investigations have been presented in [3-6]. In order to design an effective impinging jet many parameters should

be considered such as velocity and temperature gradients in the flow besides to have exact results we have to try various turbulence models and compare the results with experimental data, then choose the best model. There are many models to simulate a turbulence flow, such as, algebraic models, one equation models, two equation models, Reynolds stress model. These types of turbulence models have been listed in increasing order of complexity and their ability to model a turbulence flow. In addition it is necessary to study the nozzles shape, because the geometry of the nozzle has noticeable effects on heat transfer rate. Many studies have been done by Webb, B. and Ma, C. [7], Lytle, D. & Webb, B. [8], Yan, X. [9], Baughn, J. & Shimizu, S. [10]. Their results was the base for others works about potentiality of prediction Behnia, M., Pameix, S. & Durbin [11] have studied numerically an axisymmetric jet with various turbulences models, his results showed that the  $V2F$  turbulence model has more exact results, therefore, he studied many nozzles shape with this turbulence model. In this paper we have presented the results of numerical simulation for normal jets with circular, rectangular and triangular nozzles with the same hydraulic diameter which impinge on a constant temperature plate, Figure [1]. In this paper, At first we have introduced the results of two-dimensional model and compare them with experimental data [12], then the most accurate model is chosen to simulate the three-dimensional impinging jet with different nozzles shapes.

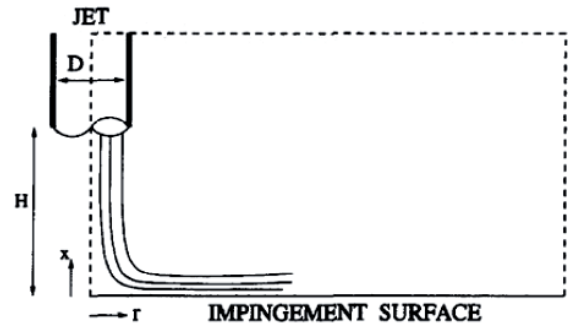


Figure.1.schematic of Cooling a hot plate with Impinging Jet

## 2. Theoretical analysis of turbulence models

In an algebraic turbulence model the velocity gradient is used as a velocity scale and some physical length is used as the length scale and is called the mixing length. It is an old model and is hardly used any more. One problem with the model is that  $l_{mix}$  is unknown and must be determined. Some modern algebraic models are Baldwin-Lomax model [2] and the Cebeci-Smith [6]. In one equation models a transport equation is often solved for the turbulent kinetic energy. To use this method we must have the turbulent length scale and often an algebraic expression is appropriate [4, 30]. This length scale is, for example, taken as proportional to the thickness of the boundary layer or the width of a wake, here the width of the jet is appropriate. The main disadvantage of this type of model is that it is not applicable to general flows since it is not possible to find a general expression for an algebraic length scale. However, some proposals have been made where the turbulent length scale is computed in a more general way [14, 30]. Two equation turbulence models are one of the most common types of turbulence models. Models like the  $k - \varepsilon$  model and the  $k - \omega$  model, have become industry standard models and are

commonly used for most types of engineering problems in addition scientists are trying to develop these models. The two equation models include two extra transport equations to represent the turbulent properties of the flow. Most often and in this paper one of the transported variables is the turbulent kinetic energy, i.e.  $k$  and the second transported variable varies depending on what type of two-equation model it is. Common choices are the turbulent dissipation,  $\varepsilon$ , or the specific dissipation,  $\omega$ , etc. The second variable can be thought of as the variable that determines the scale of the turbulence (length-scale or time-scale) As mentioned above in this paper we have studied on the ability of the turbulence models to predict the heat transfer rate and to choose the best model for simulating the three dimensional model.

### 3. Modeling the problem

Turbulent impinging jets have complex features due to entrainment, stagnation and high streamline curvature. The configuration of an impinging jet is shown in figure .2. the resulting flow field can be broken up into three main regions, the free jet, impingement and wall jet regions Saniei [7]). In the free jet region, the structure and properties of the flow are very similar to a jet of fluid flowing into an unbounded domain. In the impingement region, predominantly due to the presence of the wall, large pressure gradients exist, which forces the fluid to rapidly change direction. This flow mechanism gives rise to a localized region that has a very high rate of heat transfer. Lastly, there is the wall jet region where the fluid flows

parallel to the plate surface leading to a radial distribution of heat transfer that depends on the development of the boundary layer on the surface of the plate.

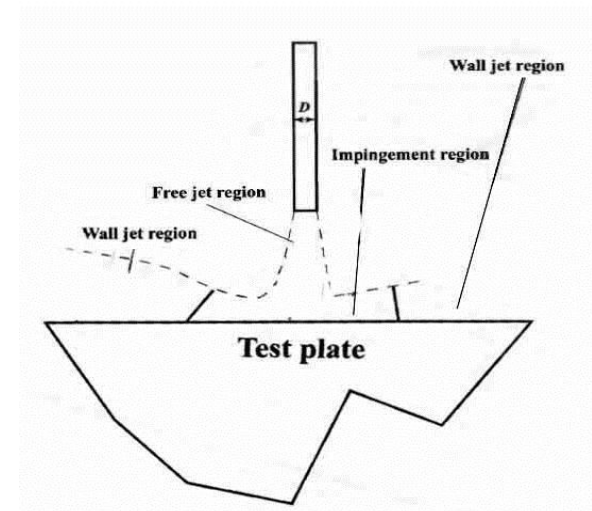


Figure.2.schematic of the three regions

### 4. The procedure of numerical solution

As we know in turbulent flow we usually divide the variables in one time-averaged part, which is independent of time, and one fluctuating part. The geometry of the problem has shown in figure.1. Air enters a nozzle with the diameter of  $D$ , velocity of  $V_0$  and temperature of  $T$ . In order to have a fully developed flow at the exit of the nozzle, we have chosen its length of  $5D$ . The distance between the nozzle in these sections have constant temperature plate is  $H$ . The relation between  $H$  and  $D$  is  $\frac{H}{D} = 2$ . The difference between the plate temperature and the jet has been assumed  $100^\circ\text{C}$ . It is necessary to mention that the hydraulic diameter of all the nozzles is the same and the Reynolds number is  $Re = 23000$  for all the cases. We got help from the nature of the problem in our two-dimensional modeling, i.e. being axisymmetric, but in three dimensional simulations we have

modeled exactly for all the areas. This study is done by Fluent 6.3.26 with finite volume method, In addition we used the Simple algorithm to formulate the velocity and pressure equations.

The boundary condition at the entrance of the nozzle is “constant velocity” and at the exit is “constant pressure”. The number of the control volumes in our two dimensional modeling is 36600, however, in the three dimensional modeling for circular, rectangular and triangular nozzle shapes this number is 1208000 and 2496000 and 2204220 respectively. Due to the symmetry in circular nozzles, the Nusselt profile is the same in every zones, nevertheless, in triangular and rectangular nozzles, so the Nusselt profile for these geometries are plotted in various angles. The lines in which the Nusselt number have calculated, have shown in Figures [2,3].

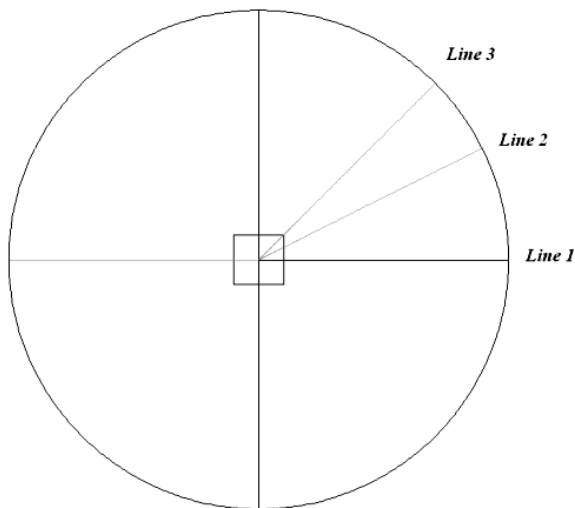


Figure.2. Schematic view for rectangular nozzle

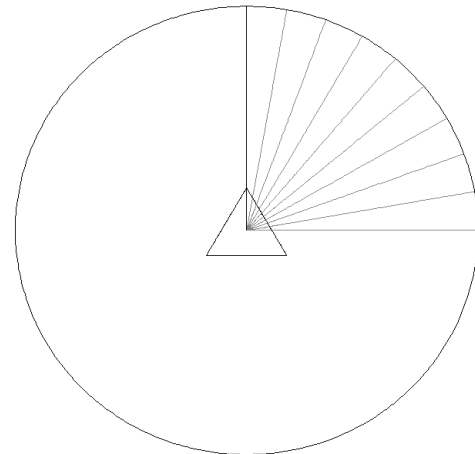


Figure.3. Schematic view for triangular nozzle

## 5. Results

The geometry and dimensions of the problem have discussed in the previous section and is listed in table 1.

Table.1. Details of the geometry and the flow

<i>Dimensions</i>	<i>Quantities</i>
Nozzles's diameter ( $D$ )	10 mm
Distance between the nozzle and the plate( $H$ )	20mm
Reynolds number( $Re$ )	23000
Temperature difference between the nozzle and the plate( $H$ ) ( $\Delta T=100$ )	100

Our results have been compared with experimental data of Yan [12] which has the same flow characteristics. Figure 4 shows the  $Y^+$  in radial direction for various turbulences models. As it can be clearly seen the amount of the  $Y^+$  for all models is less than 5 [20].

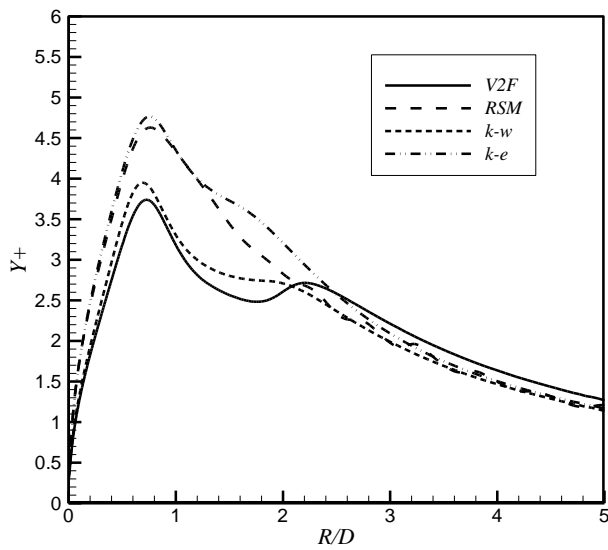


Figure.4.  $Y^+$  profile on a flat plate

In figure.5, we have compared the results of our simulating with different turbulence models with experimental data. Considering the graph, it is obvious that the  $V2F$  model shows the best results and the results of  $k - \omega$  and  $SST$  are acceptable as well but the  $k - \epsilon$  and  $RSM$  models significantly overpredict the local Nusselt number.

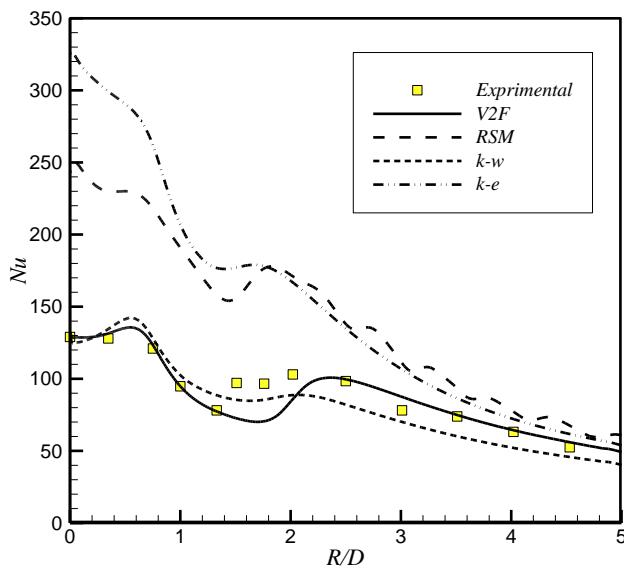


Figure.5. The profile of the local Nusselt number with Different models and experimental data

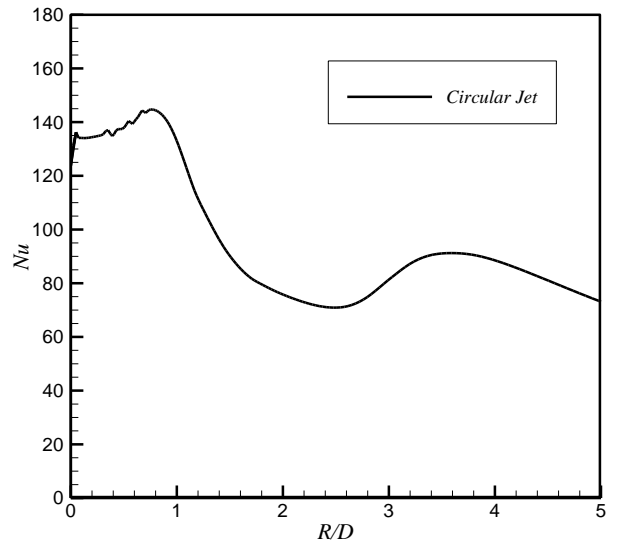


Figure.6. Variation of Nusselt number circular nozzle

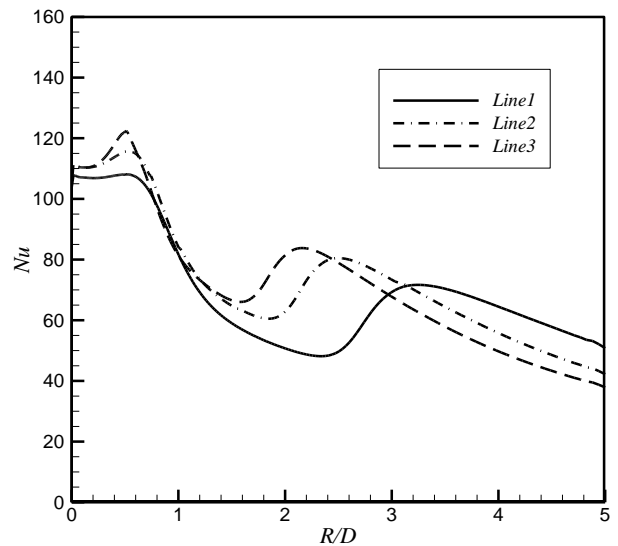


Figure.7. Variation of Nusselt number rectangular nozzle

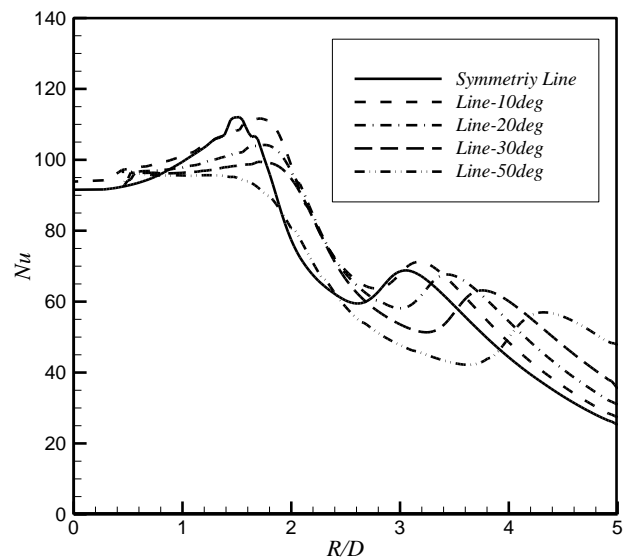


Figure.8. Variation of Nusselt number triangular nozzle

As figure .7. shows, the Nusselt number has its maximum in [same] and decreases with decreasing in the angle .We can see a 20 % reduction in heat transfer rate with changing the circular nozzle with rectangular nozzle. This trend can be realized with replacing the rectangular shape nozzle with triangular one (figures 6 and 8)..

## 6. Conclusion

In this paper, we have simulated a normal impinging Jet on a flat plate with circular, rectangular and triangular nozzle shapes with same hydraulic diameter with various turbulence models. At first the problem was simulated by the  $k - \varepsilon$  model, the  $k - \omega$  model, the  $V2F$  model and the  $RSM$  model and our result of the two dimensional modeling was compared with experimental data in order to choose the best model for our next step study. After choosing the best model which was the  $V2F$  model we simulated the problem with this model in three dimensions. In Future work we want to try on other Section Like Ellipse and others.

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