Computation of tabs and wing generator modification on temperature distribution and flow of free jet

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Abstract. The mixing process is important to improve the performance of jet-engineering equipment. The purpose research, aim to study temperature distribution might be simulate mixing layer of jet flow with surrounding fluid. In this study measure the temperature at the position the jet exit. Z =1D, 2D, 4D and 6D. Calculate the temperature coefficient and a computational fluid dynamic (CFD) using ANSYS, Fluent (V.15.0) was selected to this computation. The investigation model was jets discharging from pipe nozzle installing wing generator having an inner diameter d=28.15 mm and wall fitted to the outlet of the jet. Promoters were attached at the nozzle exit. 4 types of turbulence promoters were triangular tab with tip angle of 45° and 90° and vortex generators with attack angle of 45° and 60°. In addition, the conventional pipe nozzle was studied to compare as base results and modifications. Installing at 2 and 4 positions give the measuring temperature. The Reynolds number of test fluid was constant at \( Re=29,500 \). Increase the strength of jet mixing was found the case of vortex generator installed with 4 positions, attack angle of 60° gives the strongest mixing in jet when comparing with the other cases.

1. Introduction

Jet mixing normally are used in many industrial and engineering applications, because their common devices and mixing efficient are require for good performance in all mixing applications. Primary applications of jet mixing include combustion industries air distribution system industrial mixing and cooling of electronic packages.

The purpose of passive techniques to enhance the mixing process for achieving the optimum performance of jet mixing. Many techniques were used surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. These techniques not require any direct input of external power source to improve the entrainment.

Indeed, jet flow have been extensively studied in previous work with demand increase the performance and how interaction of the media between the jet fluid and surrounding fluid [1,2]. The Parameter Which affects the characteristics of independent jets[3,4].When the Reynolds number is higher, the flow pattern become turbulent which eddy or swirl occurs reverse current in the liquid better mixture and faster. However, increase the turbulent is require pumping power.

The insert tab or wing vortex generator were affects to the mixing of layers characteristics. Then indicates for mixing jet flow and surrounding [5,6].
The previous research show decrease of temperature or flux the jet mass flow that indicates higher induction of the mixture[7]. In addition, research has measuring intensity fluid in position per time and define volume flow rate of plane [8, 9].

The work presents investigates the effects of tab enhancement and vortex generators region exit nozzle. This research to compare experimental data and numerically investigate flow and reduction of media temperature which indicate mixing flow layers. The results will be compared to the case of conventional jet under the same of mass flow rate.

2. Experimental setup and method

2.1. Experimental model and parameters

The experimental setup of the jet discharging from the round pipe and vortex generator arrangement is shown in figure 1. An origin of the Cartesian coordinates was located on the probe measure velocity as shows in Fig.1. The X-, Y-axes are normal to the axial jet, and Z-axis is identical direction to the axial jet.

![Computational model and boundary conditions](image)

**Figure 1.** Computational model and boundary conditions.

2.2. Experimental setup

The experiment was conducted for jet from round pipe with installing tabs and vortex generator at jet outlet. The 4 types of configuration and orientation at jet outlet are shown in Figure 2. The opposite positions of delta tabs insert with 90° and 45° and 4 positions of delta tabs with 45°. The conventional pipe without tab was also studied to compare the results of the jet with delta tabs. The comparison of mixing layer characteristics on the constant jet mass flow rate (Re=29,500). During the pipe with delta test run, the jet mass flow rate was controlled in based on the identical with the conventional round pipe for the required Reynolds number. The inner diameter of round pipe was D=28.15 mm, and measuring distance at jet outlet were H=1D, 2D, 4D and 6D.
Figure 2. Computational model and boundary conditions.

2.3. Data reduction
For average temperature (T), each point can be calculated from the following equation.

\[ \bar{T} = \frac{\sum_{i=1}^{N} T_i}{N} \]  

(1)

Temperature coefficient (\( \eta \)) can be calculated from the following relationship

\[ \eta = \frac{\bar{T} - T_\alpha}{T_j - T_\alpha} \]  

(2)

where \( T_i \) is the temperature measured at any time
\( N \) is the amount of data
\( T_\alpha \) is the ambient temperature
\( T_j \) is the jet temperature

3. Numerical Simulation

3.1. Computational model and boundary conditions
ANSYS FLUENT (version 15.0) was adopted in the numerical simulation programming. Computational model were divided in three sections and boundary conditions as shown in Figure 3. The first section were included the main pipe nozzles diameter \( d = 28.15 \) mm. The air-induced ducts were assembled at the end of main pipe nozzle in the second section.
The length (L), inner diameter (D) of air-induced duct and the measuring probe distance (H) were fixed at H=1D, 2D, 4D and 6D, respectively. The details of boundary conditions were summarized in Table 1.

3.2. Grid generation and grid dependency

The rectangular grid was mainly applied in this numerical model. The grids in region having high velocity gradient as near pipe nozzles surface were finely controlled. The generating grid on Z-X plane at center of nozzle is shown in Figure 4. The number of generated grid was varied to achieve an accurate solution by considering the dimensionless wall distances ($y^+$) of the first node less than 1, calculated from

$$y^+ = \frac{y_j u_t}{v}$$

(3)

Where $y^+$ was the distance of the first node to the wall, $u_t$ was shear velocity, $y_j$ is the distance to the nearest wall and $v$ is the kinematic viscosity of air.

Figure 3. The diagram of experimental setup

Table 1. The details of boundary conditions

| Boundary condition                  | Define                        |
|------------------------------------|-------------------------------|
| Constant velocity inlet           | 16 ms⁻¹ (Re=29,500)           |
| Front and side surface             | Pressure Outlet               |
| Top and bottom surfaces            | Pressure Outlet               |

The length (L), inner diameter (D) of air-induced duct and the measuring probe distance (H) were fixed at H=1D, 2D, 4D and 6D, respectively. The details of boundary conditions were summarized in Table 1.
Figure 4. Computational model and boundary conditions.

The effects of grid dependency on $y^+$ distribution on the target surface passing. In this model, the number of grids at 767,365 elements was selected to numerical simulation. Because of the grids can be processed as similar square grid of 1,085,907 nodes is shown in Figure 5.

Figure 5. Generated rectangular grid for the numerical model.

3.3. Calculation method and algorithm
Computations were conducted by solving Reynolds averaged continuity and Navier-Stokes equations under existing boundary conditions. The SST k-ω turbulence model was selected for applying in this simulation. Since, this turbulence model has been adopted in solving many numerical simulations of jet problems. More accurately predicted the solutions of jet mixing problems with moderate computation cost. The SIMPLE algorithm was used with second order upwind scheme for all spatial discretization. The convergence of iterative solution was insured when the residual of all the
variables was less than the specified values. The specified value was $1 \times 10^{-5}$ for continuity and momentum equations.

4. Results and discussion

This part presents the results of flow characteristics and temperature distribution characteristics.

4.1. Flow characteristics

Figure 6 shows the distribution of the velocity vector of the conventional jet found that distribution was quite symmetrical for all case. The velocity for 2 position flow direct position tab. The potential core has decrees area when installation triangular tab. However, triangular tab tip $90^\circ$ has increase velocity and potential core region is distorted. Increasing triangular tab tip to 4 number as shown in Figure 7, it was found that the potential core are distorted cross shape and velocity flow of triangular tab tip $45^\circ$ increasing. When adjust attack angle are $45^\circ$ and $90^\circ$ effect surrounding air is induce near of vortex generator position.

![Image](image1.png)

**Figure 6.** Vector of conventional and modification of jet nozzle on X-Y plane of position Z=1D, Vj=16 m/s (CFD results, Re=29,500).

![Image](image2.png)

**Figure 7.** Vector of modification of jet nozzle at 4 position on X-Y plane of position Z=1D, Vj=16 m/s (CFD results, Re=29,500).
Figure 8. Vector of modification of jet nozzle with attack angle on X-Y plane of position Z=1D, Vj=16 m/s (CFD results, Re=29,500).

Figure 9. Vector of modification of jet nozzle at 4 position on X-Y plane of position Z=1D, Vj=16 m/s (CFD results, Re=29,500).

4.2 Temperature distribution characteristics

Distribution of temperature coefficients of free conventional jets was measured by the thermocouple with various points and input to calculated using equations (1 and 2).

The area the temperature coefficient is high represents the potential core of the jet and the low temperature coefficient represents the area the jet mixing with air surrounding. In the experiments, the Reynolds number of fixed to constant jet mass flow rate (Re=29,500). The jet temperature and ambient air temperature were Tj and Ta respectively on the XY plane. Each image shows the distribution of temperature coefficients at the distance from the outlet jet to Z=1D, 2D, 4D and 6D.

In figure 10 to 18 show temperature distribution characteristics with various tab and attack angle.

For all Temperature distribution characteristics divided into 3 regions, first the temperature coefficient is higher (\(\eta>0.85\)) occurs at the center of the jet (Potential core). Second, the temperature coefficients is medium (0.85\(\leq\eta\leq0.45\)), main reason shear layer effect on jet flow mixing with air ambient then reduce the temperature coefficient. Third, the range of temperature coefficients is low (\(\eta\leq0.45\)). The area around the jet mixing with the surrounding air, so that the temperature coefficient of the jet near the surrounding air.

Conventional jet case distance from exit jet to Z=6D has potential core (\(\eta>0.9\)). For other installation Tab and wing vortex generator has distorted potential core at position Z=2D. The
phenomenon of jet mixing with ambient air has disappeared. When distance to $Z = 6D$ the distribution coefficient was similar conventional jet case.

The distribution temperature coefficient wide region distance from exit nozzle to $Z = 4D$ for the attack angles $60^\circ$ at 2 position. When Installation 4 position for wing generator has attack angle $60^\circ$ increase the mixing layer. However, The effect of installing attack at the outlet causes a mixture between the jet and the surrounding fluid. More than similar conventional jet.

![Figure 10. The temperature distribution characteristics ($\eta$) of the free jet conventional. On the XY plane at various z positions.](image)
Figure 11. The temperature distribution characteristics ($\eta$) of the delta tabs generator with 45° at 4 position. On the XY plane at various z positions.

Figure 12. The temperature distribution characteristics ($\eta$) of the delta tabs generator with 90°. On the XY plane at various z positions.
Figure 13. The temperature distribution characteristics ($\eta$) of the delta tabs generator with 45°. On the XY plane at various z positions.

Figure 14. The temperature distribution characteristics ($\eta$) of the delta tabs generator with 90°. On the XY plane at various z positions.
Figure 15. The temperature distribution characteristics ($\eta$) of the wing generator attack angle $45^\circ$. On the XY plane at various z positions.

Figure 16. The temperature distribution characteristics ($\eta$) of the wing generator attack angle $60^\circ$. On the XY plane at various z positions.
Figure 17. The temperature distribution characteristics ($\eta$) of the wing generator attack angle $45^\circ$. On the XY plane at various z positions.

Figure 18. The temperature distribution characteristics ($\eta$) of the wing generator attack angle $60^\circ$. On the XY plane at various z positions.
5. Conclusions
In this paper, flow and Distribution of temperature coefficients characteristics of modification jet nozzle were studied experimentally and numerically. The results concluded as follow:

1) Tabs and wing generator attack are improve the flow cross section high intensity flow velocity and direction than conventional jet.
2) Tabs insert has high distribution of temperature coefficients than that of generator attack. The high temperature distribution is delta tabs generator with 90° due to high turbulent intensity on the flow area .
3) Attack angle of 60° have highest of temperature distribution then improve the mixing jet when compared with the other cases. Due to large of flow intensity.

For future work would be simulation study on effect of counter rotating vortex at near field region with temperature distribution.

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