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TURBULENCE MODELS APPLICATION IN AIR FLOW OF CROSSFLOW TURBINE

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ABSTRACT

Using the CFD method as the initial analysis for experiments has more benefits, including saving time and costs. The variable of flow parameters and geometry can be easily developed to get the desired results. However, research is needed to improve the accuracy of the results and the optimality of the calculation process; the study of complex turbulent flow modelling becomes very important. The k-ε model and renormalization group (RNG) k-ε model are widely used in research to produce the appropriate models and develop the constants value. This turbulent flow modelling research was conducted to improve the result accuracy and the calculation process optimality in the turbulent flow of crossflow turbine. Research was done by comparing the simulation results of k-ε model with different constants and RNG k-ε model. The k-ε model with kinetic Prandtl 0.8, 0.9, 1, 1.1, 1.2 and the RNG k-ε model show different results for predicting the average pressure and velocity distribution in the turbulent flow of crossflow turbine, and likewise for turbulent parameters. The RNG k-ε model has more accuracy than the k-ε model, although the k-ε model's simulation time is quite short. Therefore, complex fluid flow recommends RNG k-ε model.

Keywords: k-ε model; RNG k-ε model; Turbulent flow

1. INTRODUCTION

Using the CFD method as the initial analysis for experiments has more benefits, including saving time and costs. For example, the variable of flow parameters and geometry can be easily developed to get the desired results. CFD simulations are used in digesters with baffle clearance variations, indicating that the baffle clearance 50 mm has the largest recirculation, which leads to better slurry mixing (Siswantara et al., 2016). A CFD method was used in the net power coefficient study of wind turbines with crossflow runners, resulting in optimal work located in a narrow band of low TSR and α reaching a value of Cp < 0.2 only (Pujol et al., 2018).

Turbulent flow occurs at Reynolds number values above Re_{crit}. The flow behavior is random and chaotic. Motion becomes intrinsically unsteady, even with constant imposed boundary conditions. The velocity and all other flow properties vary in a random and chaotic way. A lot of turbulence model development occurs in CFD, so the model is in the RANS group.

The most widely used turbulence models are the k-ε and RNG k-ε models; the former is one of the simplest turbulence models, only requiring the input processes of boundary conditions. The k-ε model is widely used for technical analysis in industry because it is quite stable and widely

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validated. However, the model's weakness is that it produces unfavorable results when used for simulating non-walled flow, large strain flow, rotating flow, and flow developed in a non-circular channel. Two additional equations in the k-ε model for turbulent flow are the kinetic energy transport equation k and the dissipation transport equation ε (Versteeg & Malalasekera, 1995). The RNG k-ε model is improved from the k-ε model (Mohammadi & Pironneau, 1993). Developed by Yakhot and Orszag, and based on the renormalization group (RNG) statistical theory, the RNG k-ε model adds some equations into the k-ε model.

Both models are widely used in research to produce the appropriate models and develop the constants value. The RNG model k-ε with the model characteristics is used to analyze cross-flow runners (Darmawan et al., 2015). The value of inverse-turbulent Prandtl number (α) 1.1 is best used to simulate turbulent flow in a curved pipe using the RNG k-ε model at Re 63800 and the r/D 1,607 (Budiarso et al., 2015). k-ε and RNG k-ε could be used to represent the combustion process phenomenon without any significant differences for the numerical analysis of gas flow in the annular combustion chamber of a Proto X-3 (Daryus et al., 2016). Three turbulence models compared in wind tunnels to predict turbulence parameters are validated with test data, revealing that the k-ε model is effective because its results are comparable to the RSM model (Gunadi et al., 2016).

This research will compare the k-ε model with different constants and the RNG k-ε model to analyze flow characteristics to improve the result accuracy and the calculation process optimality in crossflow turbines.

2. METHODS

2.1. Turbulence Models

Below are the two additional equations in the k-ε model for turbulent flow; the kinetic energy transport equation k is shown in Equation 1, and the dissipation transport equation ε is shown in Equation 2 (Versteeg & Malalasekera, 1995).

$$\frac{\partial(\rho k)}{\partial t} + div\,(\rho\, k\mathbf{U}) = div\left[\frac{\mu_t}{\sigma_k}\, grad\; k\right] + 2\mu_t E_{ij}.E_{ij} - \rho\varepsilon \tag{1}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + div\,(\rho\varepsilon\,\mathbf{U}) = div\left[\frac{\mu_t}{\sigma_\varepsilon}\, grad\;\;\varepsilon\right] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t\, E_{ij}.E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{2}$$

where:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{3}$$

ρ is density, **U** is the velocity vector, μ_t is the viscosity eddy and E_{ij} is the average speed of deformation. If *i* or *j* = 1, it relates to the x-direction; if *i* or *j* = 2, it relates to the y-direction; and if *i* or *j* = 3, it relates to the z-direction. C_μ, σ_k, σ_ε, $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are constants.

There are also two additional equations in the RNG k-ε model for turbulent flow; the kinetic energy transport equation k is shown in Equation 4, and the transport equation dissipation ε is shown in Equation 5 (Yakhot et al., 1992).

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial}{\partial x_i}(\rho\, k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\varepsilon \tag{4}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}P_k-C_{2\varepsilon}^{*}\rho\frac{\varepsilon^2}{k} \tag{5}$$

where:

$$P_k=-\rho\overline{u'_i\,u'_j}\frac{\partial u_j}{\partial x_i} \tag{6}$$

$$C_{2\varepsilon}^{*}=C_{2\varepsilon}+\frac{C_\mu\eta^3(1-\eta/\eta_0)}{1+\beta\eta^3} \tag{7}$$

$\eta=Sk/\varepsilon$ and $S=(2S_{ij}S_{ij})^{1/2}$

S is the average rate of strain, and C_μ, σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$, η_0 and β are constants.

2.2. Geometry

Geometry sketches for crossflow turbines can be seen in Figure 1. The geometry shows the simulation domain that will be performed.

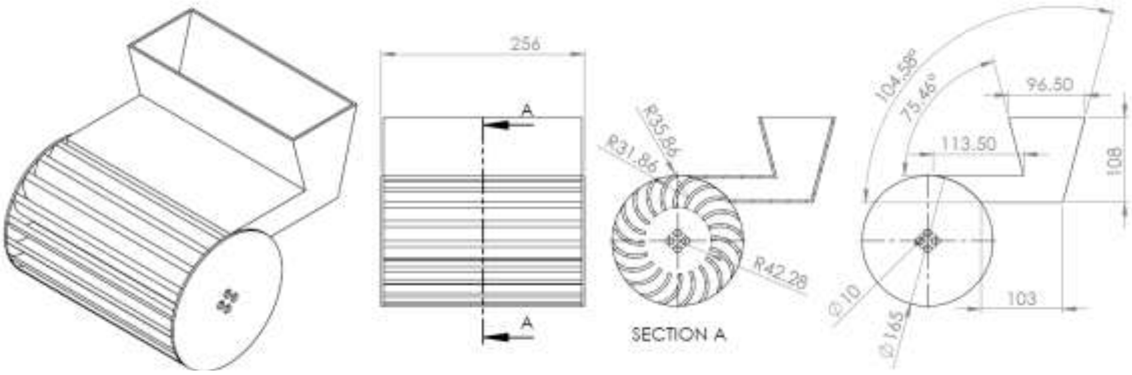

Figure 1 Crossflow turbine

2.3. Meshing and Boundary Conditions

A 3D model was used for the simulation. The grid used was a structured cell with dimensions 199×89×2. Figure 2 shows the construction grid. Grid dependence was tested on various grid dimensions, where the test results were consistent, not influenced by grid size.

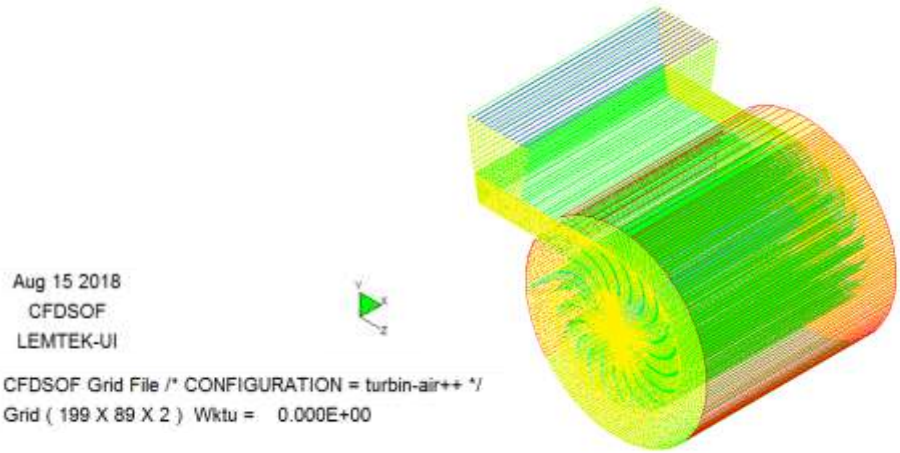

Figure 2 Meshing simulation model

The parameters data as follows:
Angular speed runner : 314.286 rad/s
Normal velocity of air inlet : 50 m/s

2.4. CFD Simulation

Simulation results verification was done by comparing the contours of the velocity simulation results with the secondary data. Figure 3 depicts the velocity contour of the simulation results once studied, showing a comparable flow pattern.

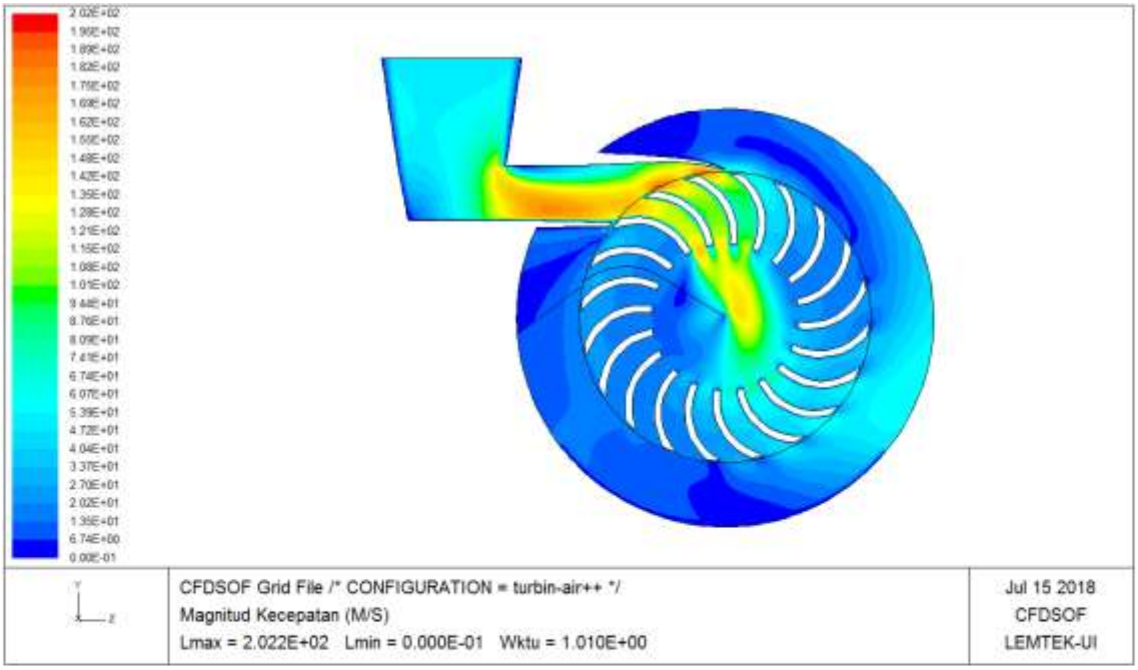

Figure 3 Velocity contour of the simulation results for crossflow turbine.

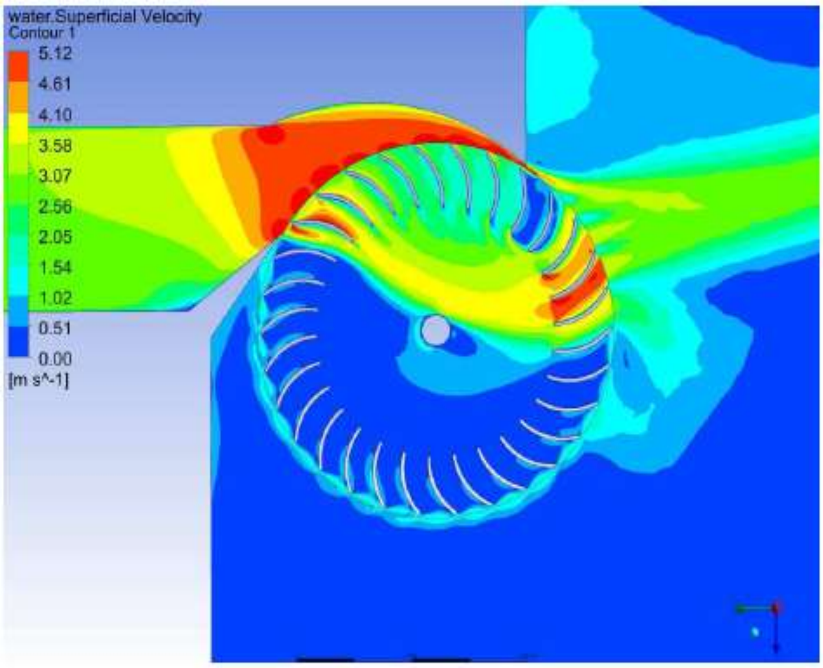

Figure 4 Contour plot of the mean water velocity magnitude for the 0.53 kw turbine (Adhikari & Wood, 2018)

3. RESULTS AND DISCUSSION

3.1. Parameter Simulation

The inlet condition is a normal velocity, where the value is 50 m/s and angular speed runner is 314.286 rad/s. The k-ε with E Prandtl 0.8, 0.9, 1, 1.1, 1.2 and RNG k-ε model were used in this simulation.

3.2. Simulation Results

Figure 5 and Figure 6 depict the pressure and the velocity profiles, respectively, from the turbine blade inlet into the turbine blade outlet of the crossflow turbine for the k-ε model with E Prandtl 0.8, 0.9, 1, 1.1, 1.2 and the RNG k-ε model. The profiles show that the simulation results of the two models are not comparable; therefore, the two turbulence models give have significantly different results for the average flow parameters of the average pressure and velocity distribution.

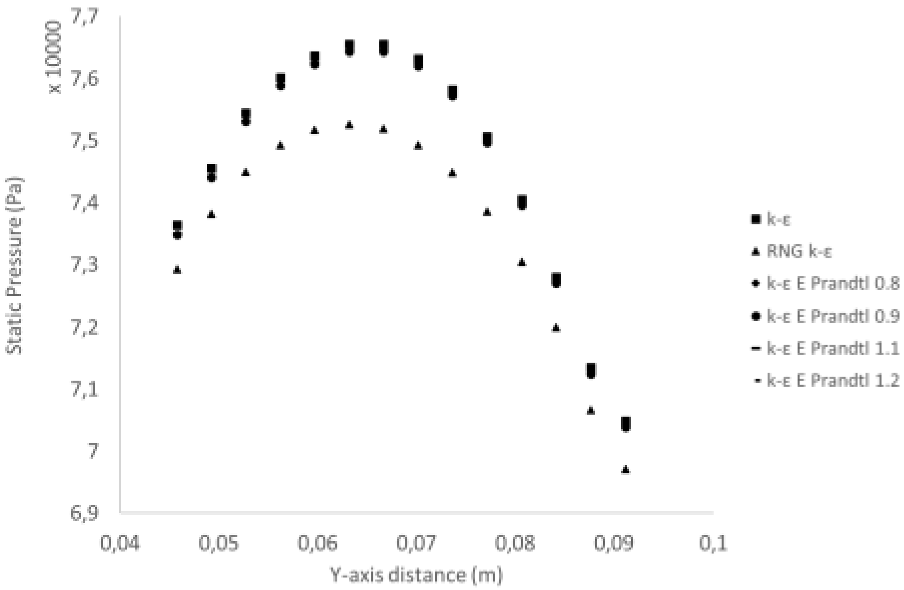

Figure 5 The pressure curve along the y-axis at the crossflow turbine blade

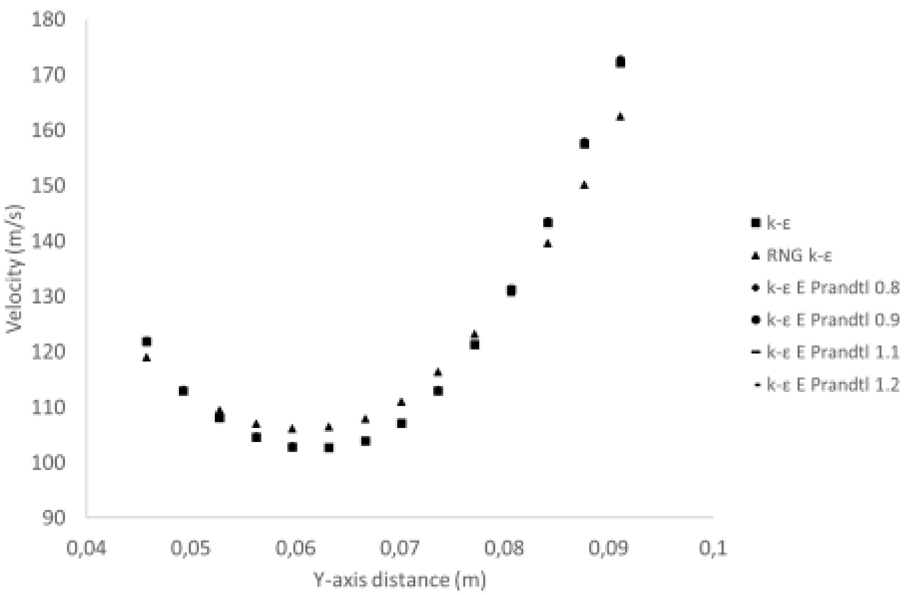

Figure 6 The velocity curve along the y-axis at the crossflow turbine blade

The simulation results for the two models' turbulent parameters look at the profiles for turbulent kinetic energy (Figure 7), turbulent dissipation rate (Figure 8) and turbulent effective viscosity (Figure 9). Simulation results for turbulent parameters show that each turbulent model gives a significant difference in results.

The RNG k-ε model has more accurate simulation results for simple to complex flow than the k-ε model. Although k-ε has advantages in terms of simplicity, until the simulation time is quite short, the model remains adequate for many applications.

The simulation results of both turbulence models are different for the average pressure and velocity distribution, as well as for turbulent parameters, such as kinetic energy, dissipation rate, and effective viscosity. These results recommend the RNG k-ε model for complex fluid flow.

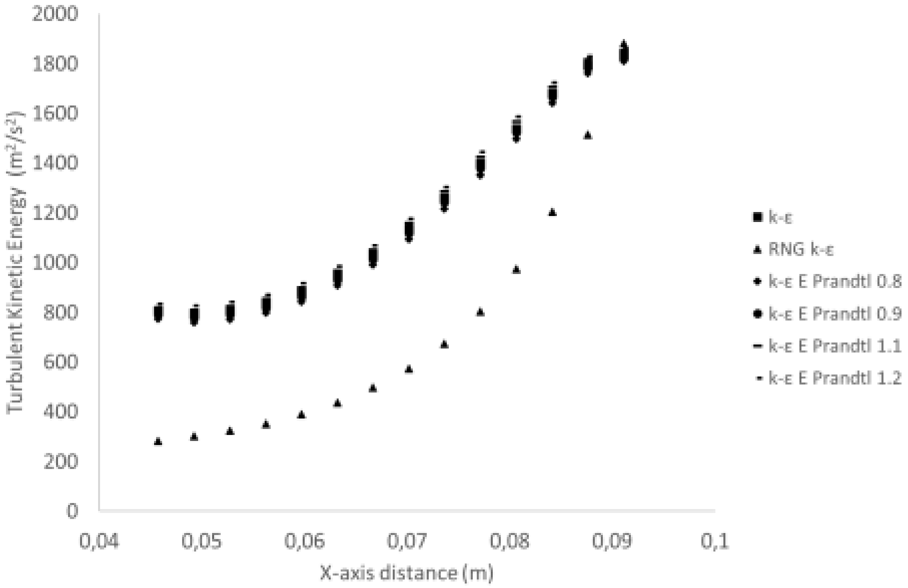

Figure 7 The turbulent kinetic energy curve along the y-axis at the crossflow turbine blade

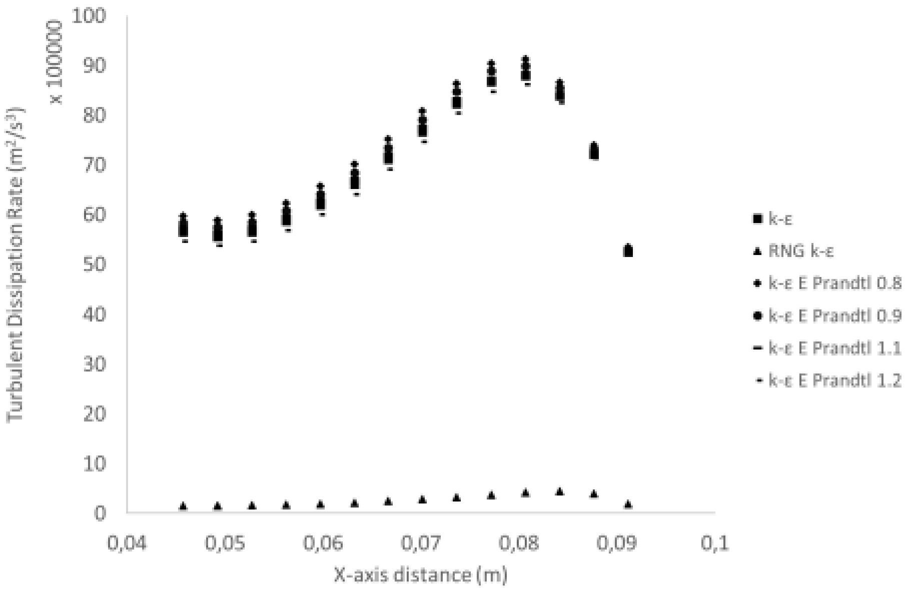

Figure 8 The turbulent dissipation rate curve along the y-axis at the crossflow turbine blade

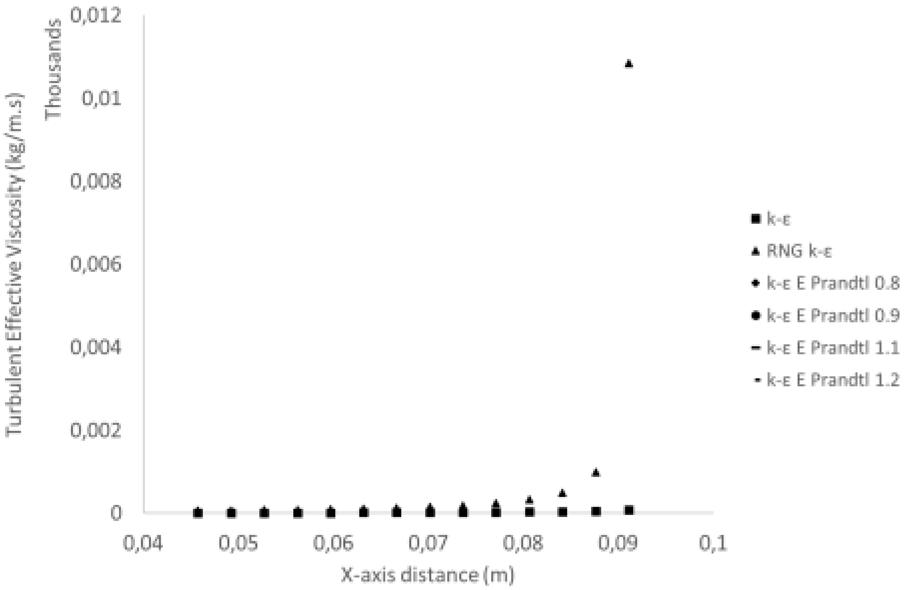

Figure 9 The turbulent effective viscosity curve along the y-axis at the crossflow turbine blade

4. CONCLUSION

This turbulent flow modelling research was conducted to improve the result accuracy and the calculation process optimality in the turbulent flow of crossflow turbine by comparing the simulation results of the k-ε and RNG k-ε models. Both model gave different results for the average pressure and velocity distribution, and for turbulent parameters. The RNG k-ε model was more accurate than the k-ε model, which requires a shorter simulation time; therefore, the RNG k-ε model is recommended for complex fluid flow.

5. ACKNOWLEDGEMENT

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