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Study of Turbulence Models Application in Crossflow Turbine Analysis

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Abstract. The CFD method, as the initial analysis has more benefits regarding experiments, including saving time and costs. Variable of flow parameters and geometry can be developed easily to get the desired results. However, research is needed to improve the accuracy of the results and the efficiency of the calculation process. The study of complex turbulent flow modeling 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 value of constants. This turbulent flow modeling research was conducted to improve the accuracy of the results and the efficiency of the calculation process in turbulent flow of crossflow turbine. Research is done by comparing the simulation results of k–ε model and RNG k–ε model. The comparison of the k–ε model and RNG k–ε model results shows different results for predicting the average pressure and velocity distribution in turbulent flow of crossflow turbine. Likewise for turbulent parameters. It can be concluded for complex fluid flow recommending RNG k–ε model.

INTRODUCTION

The CFD method, as the initial analysis has more benefits regarding experiments, including saving time and costs. For example, variable of flow parameters and geometry can be developed easily to get the desired results. Quite a lot of development of turbulence models in CFD So is the models in the RANS group. Turbulence models are widely used is the k–ε and RNG k–ε. The k–ε turbulence model is a simple turbulence model only requires the input process of boundary conditions. The k–ε turbulence model are widely used for technical analysis in industry, are quite stable and widely validated [1]. The weakness of the k–ε model is unfavorable results when used for simulating non-walled flow, large strain flow, rotating flow and flow developed in a non-circular channel [1]. The RNG k–ε turbulence model is improved from k–ε turbulence model [2]. Developed by Yakhot and Orszag based on the renormalization group (RNG) statistical theory. The RNG k–ε turbulence model adds some equations into the k–ε model.

This research is done by comparing the k–ε and RNG k–ε turbulence models in analyzing flow characteristics in crossflow turbines.

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METHODS

Turbulence Models

The k–ε and the RNG k–ε turbulence models used in this research.

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

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

where:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \qquad \text{iii)}$$

ρ is density, $\mathbf{U}$ 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.

Two additional transport equations in the RNG k–ε turbulence model; the kinetic energy transport equation, k iv), and the dissipation transport equation, ε v) [3].

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

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\;\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}P_k - C^*_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad \text{v)}$$

Where;

$$P_k = -\rho\overline{u'_i\,u'_j}\frac{\partial u_j}{\partial x_i} \qquad \text{vi)}$$

$$C^*_{2\varepsilon} = C_{2\varepsilon} + \frac{C_\mu\eta^3(1-\eta/\eta_0)}{1+\beta\eta^3} \qquad \text{vii)}$$

$\eta = Sk/\varepsilon$ 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

Geometry

The geometry of the crossflow turbine is shown in Figure 1.

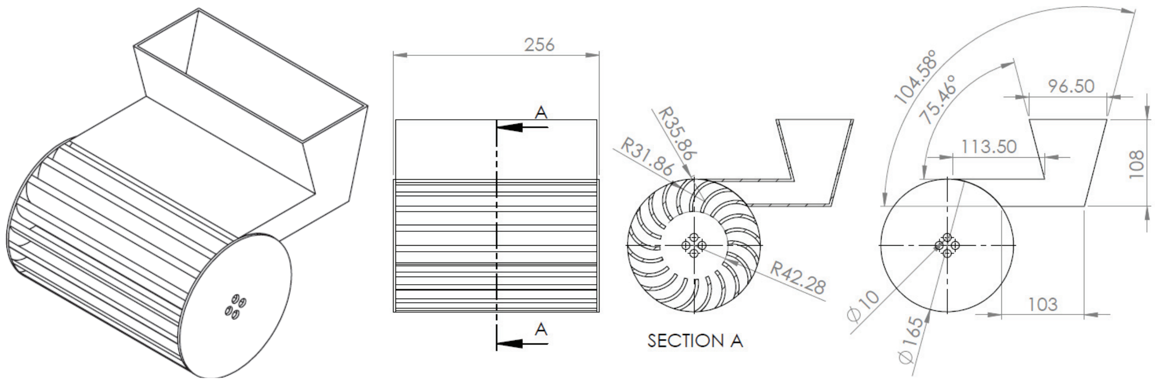

Figure 1 Crossflow Turbine

Meshing and Boundary Conditions

A 3-dimensional model was used for the simulation. The grid used was a type of structured cell with dimensions 199x89x2. Construction grid is shown in Figure 2. Grid dependence is tested on various grid dimensions, where the test results are consistent, not influenced by grid size.

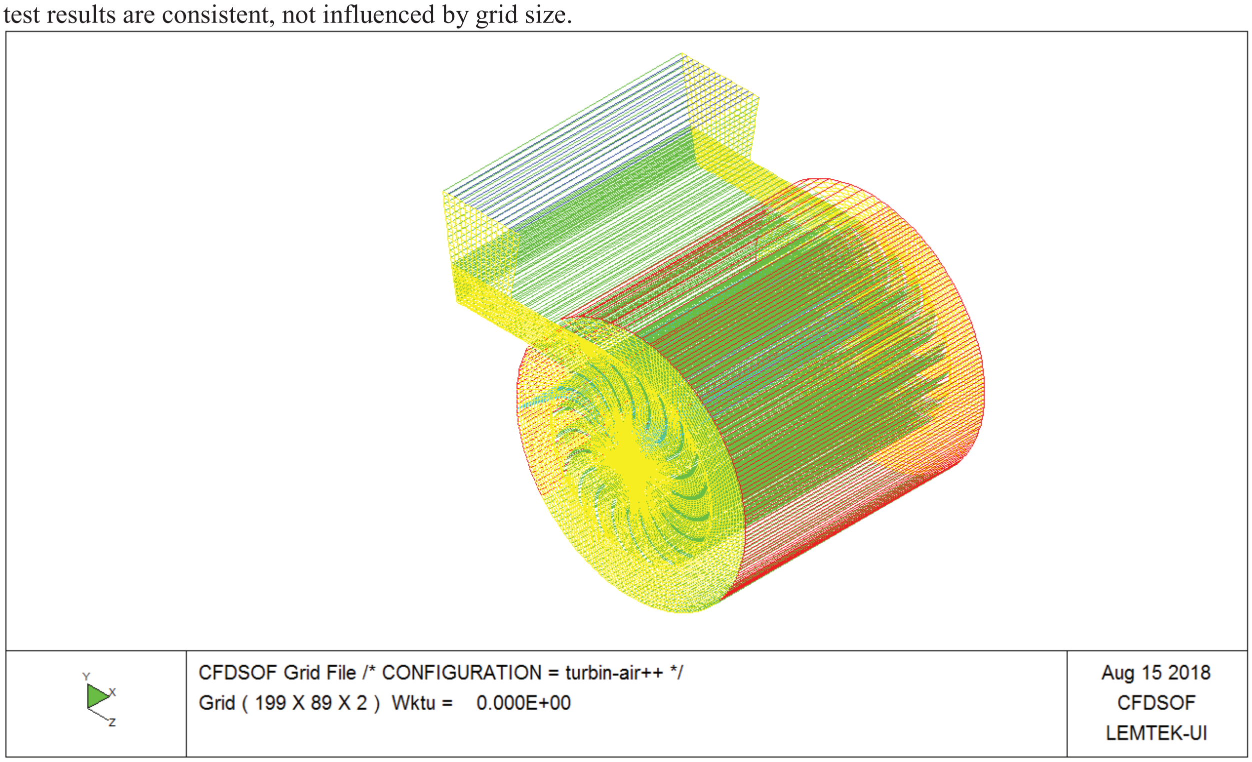

Figure 2 Meshing simulation model

The parameters data as follows:
angular speed runner : 314.286 rad/s
normal velocity of water inlet : 50 m/s

CFD Simulation

Verification of simulation results is done by comparing the velocity contour of the simulation results with the secondary data. Figure 3 is the velocity contour of the simulation results and Figure 4 is the velocity contour of the simulation results once studied, showing a comparable flow pattern.

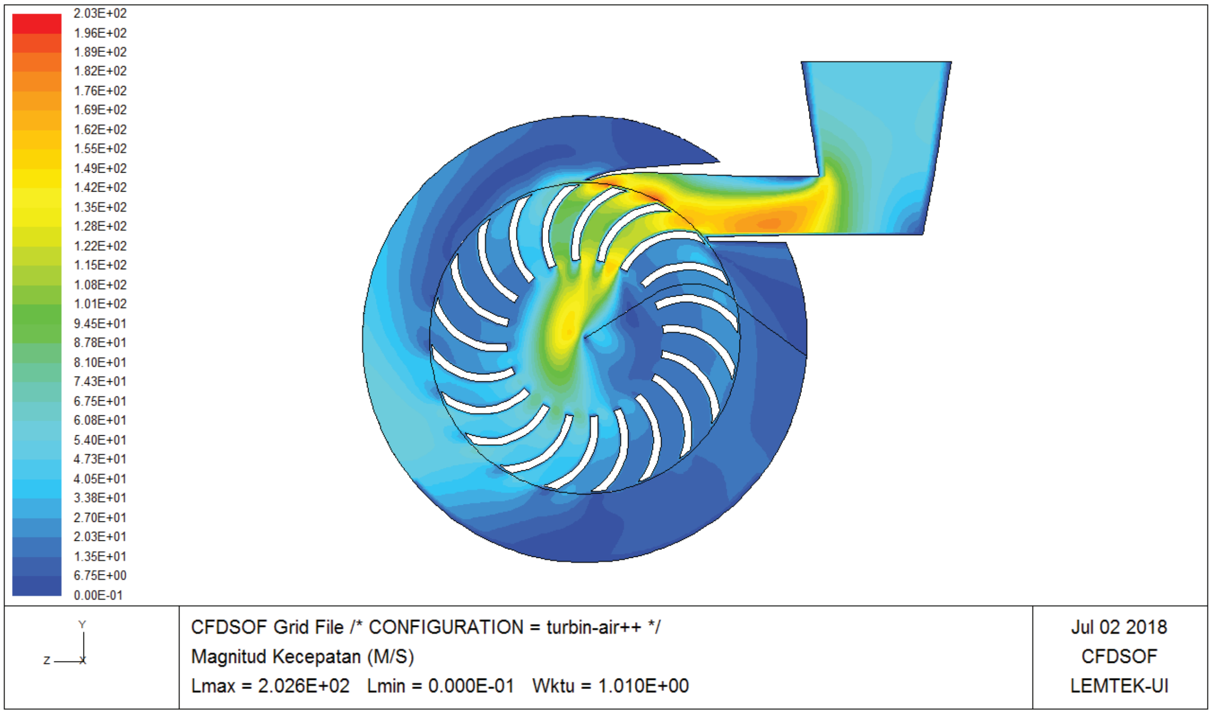

Figure 3 Velocity Contour of the Simulation Results for Crossflow Turbine.

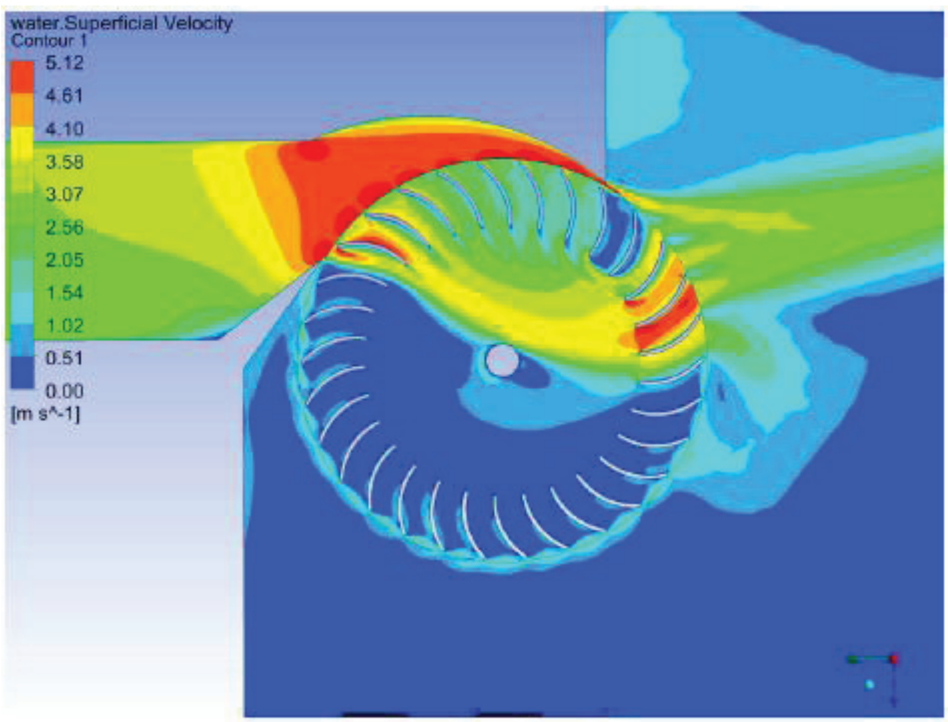

Figure 4 Contour Plot of the Magnitude of Mean Water Velocity for the 0.53 kW Turbine [4].

RESULTS AND DISCUSSION

The inlet is a normal velocity where the value is 50 m/s and angular speed runner is 314.286 rad/s. The k–ε and RNG k–ε turbulent models used in this simulation.

The pressure profiles in Figure 5 and the velocity profiles in Figure 6 from the turbine blade inlet into the turbine blade outlet of the crossflow turbine for two types of turbulence models. Both profiles show that the results of the two models are not comparable. From the results of these simulations, it can be concluded that the two turbulent models give significant differences in results on the average parameters of flow for the average pressure and velocity distribution.

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

The RNG k–ε turbulent model is a model that has more accurate simulation results for simple to complex flow than k–ε turbulent models, although the k–ε has advantages in terms of simplicity, until the simulation time is quite short, it remains adequate for many applications.

The simulation results of both turbulent models give different results for the average pressure and velocity distribution. Likewise for turbulent parameters, such as kinetic energy, dissipation rate, and effective viscosity, the simulation results are not the same. Simulation results show for complex fluid flow recommending RNG k–ε model.

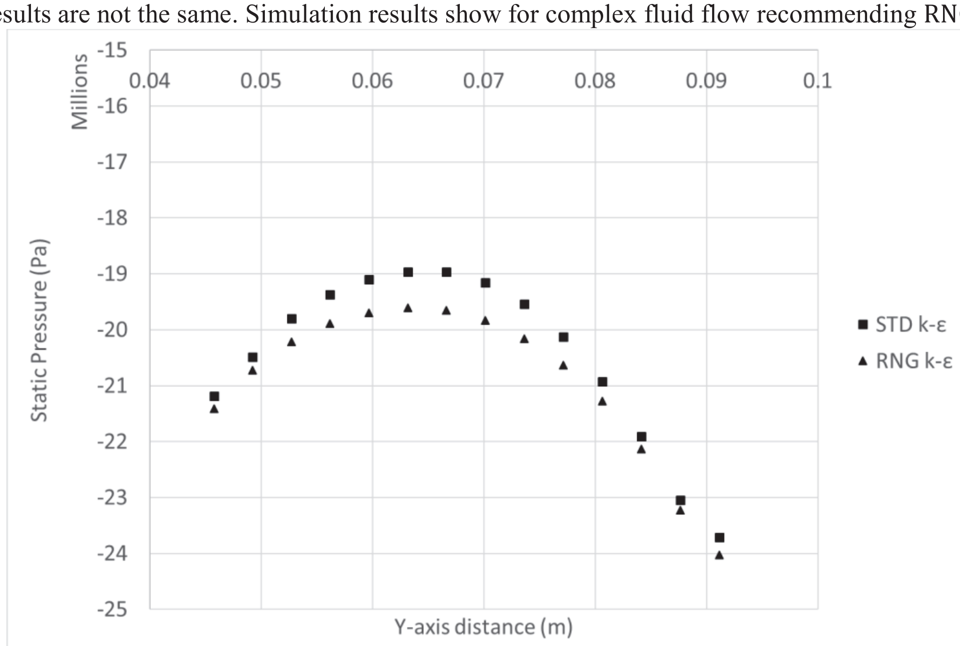

Figure 5 The pressure profiles along the inlet and outlet of the crossflow turbine blade.

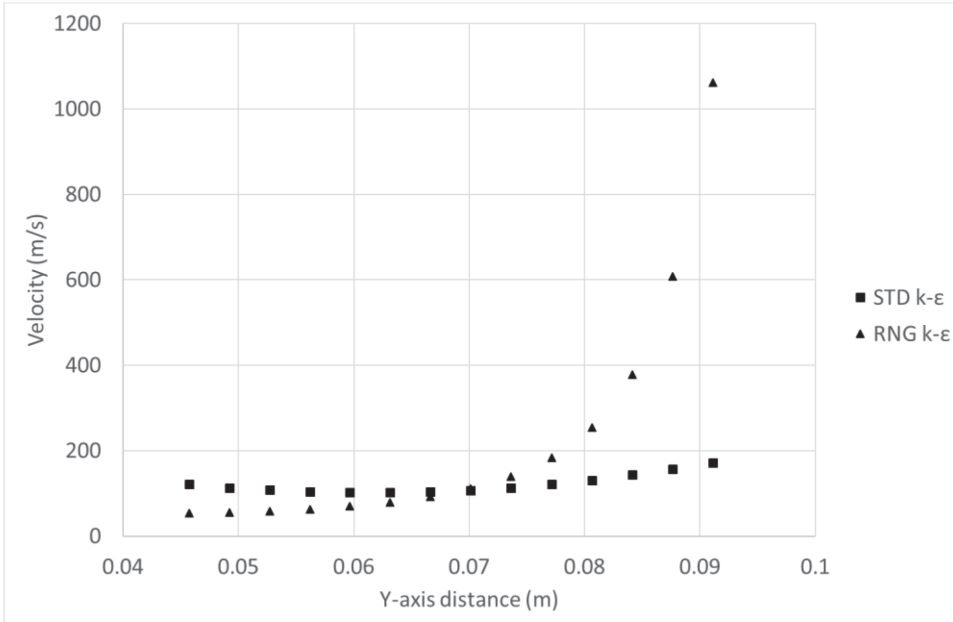

Figure 6 The velocity profiles along the inlet and outlet of the crossflow turbine blade.

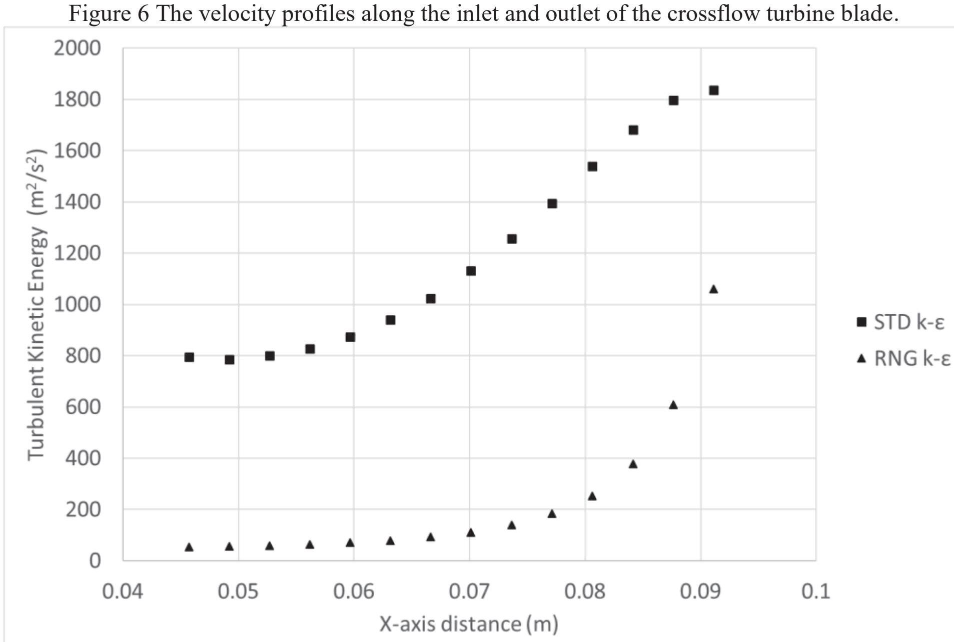

Figure 7 The turbulent kinetic energy profiles along the inlet and outlet of the crossflow turbine blade.

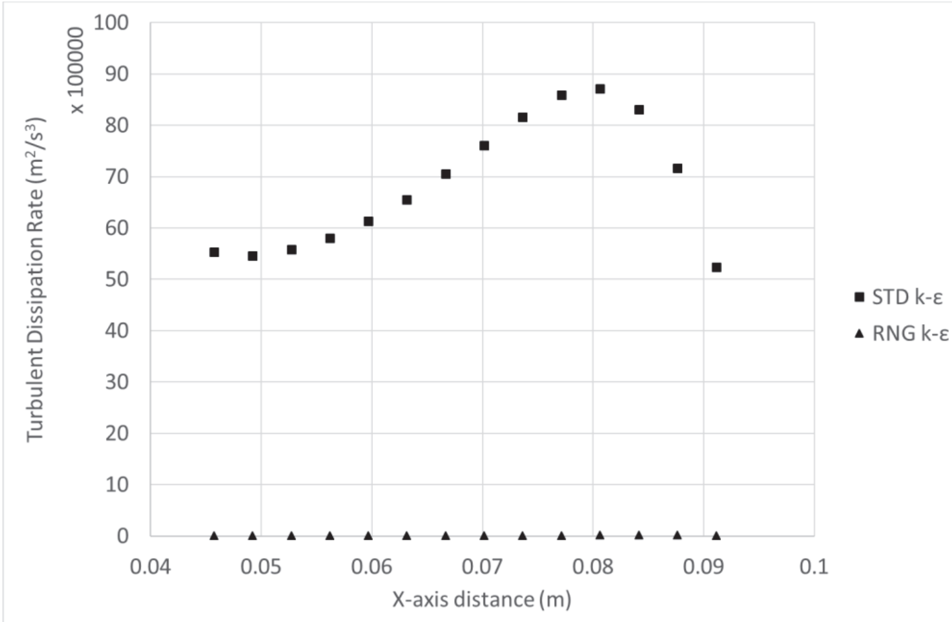

Figure 8 The turbulent dissipation rate profiles along the inlet and outlet of the crossflow turbine blade.

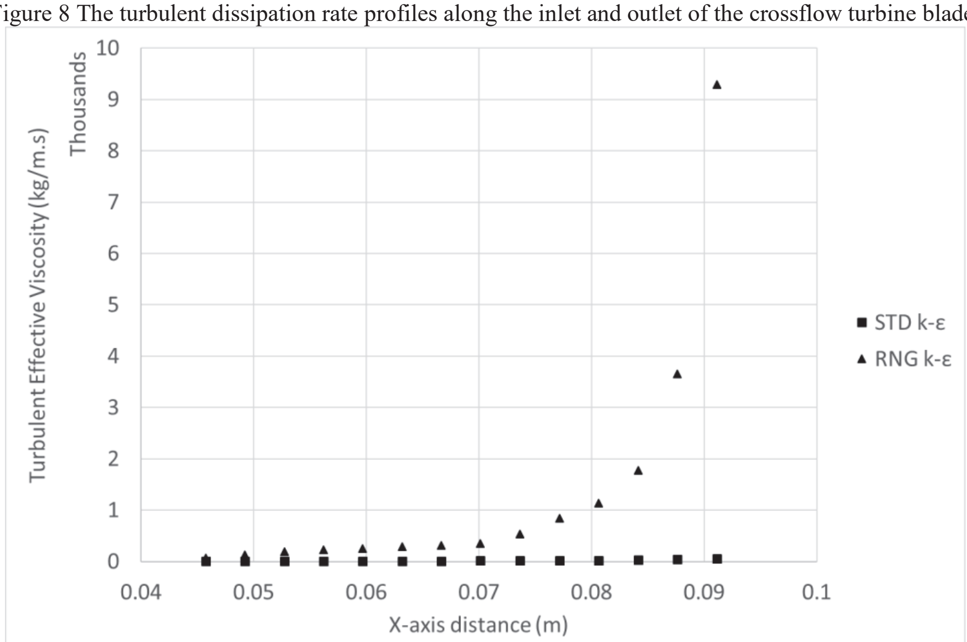

Figure 9 The turbulent effective viscosity profiles along the inlet and outlet of the crossflow turbine blade.

CONCLUSION

This turbulent flow modeling research was conducted to improve the accuracy of the results and the efficiency of the calculation process in turbulent flow of crossflow turbine. The research was conducted by comparing the simulation results of k–ε model and RNG k–ε model. The k–ε and RNG k–ε turbulence models give different results for the average pressure and velocity distribution. Likewise for turbulent parameters, such as kinetic energy, dissipation rate, and effective viscosity, the simulation results are not the same. Simulation results show for complex fluid flow recommending RNG k–ε model.

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REFERENCES

1. H. K. Versteeg and W. Malalasekera, “An Introduction to Computational Fluid Dynamics - The Finite Volume Method,” *Fluid flow handbook. McGraw-Hill …*. p. 267, 1995.
2. B. Mohammadi and O. Pironneau, “Analysis of the k-epsilon turbulence model,” 1993.
3. V. Yakhot, S. A. Orszag, S. Thangam, T. B. Gatski, and C. G. Speziale, *Develoment of Turbulence Models for Sher Flows by a Double Expansion Technique*. 1992.
4. R. Adhikari and D. Wood, “energies The Design of High Efficiency Crossflow Hydro Turbines : A Review and Extension,” pp. 1–18, 2018.