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The Study of 3D Simulation on Heat Transfer Enhancement on Fin Tube Heat Exchanger Using Delta Wing and Winglet Vortex Generators

Stefan mardikus[1, *], Claudia Agata Putri[1] Michael Seen[1], Rines[1],
Y.B. Lukiyanto[1], Doddy Purwadianto[1], Heryoga Winarbawa[1],
Gilang Argya Dyaksa[1], Wibowo Kusbandono[1]

[1]*Faculty of Science and Technology, Sanata Dharma University,*
Yogyakarta, 55598, Indonesia

[*]*Corresponding Author: stefan@usd.ac.id*

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Abstract

The vortex generator is one of the methods to improve heat transfer augmentation on flow characteristics in the air side of the fin and tube heat exchanger. There are some models of vortex generators to produce longitudinal vortices when the airflow passes the surface of the vortex generator. In the previous studies, the longitudinal vortices were able to reduce the wake region phenomenon behind the tube heat exchanger. This research aims to investigate the thermal performance of heat transfer on the collaboration between two models of vortex generators namely delta wing and winglet vortex generators on plate fin and tube heat exchanger. The simulation used four models (1) without the vortex generator (2) with the delta wing vortex generators (3) with delta winglet (4) with the combination of delta wing and winglet. The study was generated with computational fluid dynamics. The boundary conditions were set in the inlet as velocity and the outlet as pressure outlet. The airflow of velocity is represented by Reynolds numbers in the range of 4000 - 8000 with an interval of 500. The wall temperature of the tube is given at 400 Kelvin and the temperature of the airflow is given at 300 Kelvin. The epsilon model was used in the turbulence model of the simulation. The result explained that the thermal performance of heat transfer on delta winglets improved the airflow to induce longitudinal vortices and then reduced the wake region to improve the heat transfer coefficient more than other vortex generator models.

Keywords: Heat Transfer, Vortex Generator, Heat Exchanger

1 Introduction

Heat Exchanger is a device that can be used to transfer energy by heat between two or more types of fluid which has a different temperature [1]. Based on the construction a heat exchanger, has four types such as tubular, plate type, extended surface, and regenerator heat exchanger. Fin and tube heat exchangers are a heat exchanger of most common and can be applied in air conditioning, heating, cooling systems, refrigerators, radiators, and also the industry of petroleum and natural gas [2]. This type has a higher heat transfer coefficient and high-pressure capacity, thus; it is better than other types of heat exchangers. On the other side, the fin and tube heat exchanger have also an obstacle to the heat transfer process in the air side because there is a wake region behind the tube heat exchanger. The wake region occurred because the momentum of the fluid stream weakened and it was difficult to cause a heat transfer [3]. The wake region can reduce the pressure drop of the stream in the heat exchanger [4]. One of the solutions to reduce the wake region is with use of vortex generators. A vortex generator is an extended surface that can produce longitudinal vortices and reduce wake regions [5]. There are some types of vortex generators such as delta wing, rectangular wing, delta winglet, and rectangular winglet [3]. Liu et al. [6] have studied using a delta winglet vortex generator with the improvement of configuration to enhance heat transfer. It showed that the wake region dramatically reduces behind the tube and it was caused by the turbulent intensity around 27.8% to 67.5% based on using the without vortex generator. Garelli et al. [7] studied the effect of delta-wing vortex generators on radiators using a numerical study. They found that the overall heat transfer increased by 12% on a single delta wing between two plates in the heat exchanger. The investigation of vortex generators for delta wing and winglet types also has been studied by Hoards. Fiebig [8]. The result showed that the extended surface for the delta winglet type is superior to the delta wings in the overall heat transfer coefficient. The experiment about curved delta winglets on the effect of geometry was investigated to determine the thermal-hydraulic performance of fin and tube heat exchangers. Song et al. [9] tried to change winglet sizes, fin pitches, and tube pitches in 15 items on fin and tube configuration. The measurement of smaller and closer vortex generators to the tube produced better thermal-hydraulic performance enhancement in the low Reynold numbers but larger vortex generators were more suitable for the high Reynold numbers. Around 15 mm x 20 mm with an angle of attack of 30º on delta winglet vortex generators has been studied by Kharge and Ghuge [10] on tube-in-tube heat exchangers, the results showed that the heat transfer performance augmented than other types of vortex generators. In the previous studies, there is no yet found study about the comparison of wing and winglet vortex generators in fin and tube heat exchangers. This study aims to investigate heat transfer performance on three model vortex generators such as types plain, wing, winglet, and a combination of wing and winglet vortex generators.

2 Model Description and Methods

In this study, the type of fin and tube heat exchanger is analyzed using computational fluid dynamics. The illustration of the fin and tube is shown in Fig. 1. There are six tubes in one line fin as in Fig. 2. The Diameter of the tube is 19 mm and the distance between one tube and another tube is 60 mm. The domain of this simulation is created in Fig. 3, with the length of the fin of 500 mm and a width of 165 mm. In Fig. 4, Four models of vortex generator (VGs) are applied such as (1) Model fin and tube heat exchanger without, (2) with wing VGs, (3) with winglet VGs, (4) a combination between wing and winglet VGs. This simulation used the variation of Reynold Numbers starting from 4000 until 8000 with intervals of 500. In the inlet domain, the fluid of air was chosen as the working fluid which has a temperature of 273 K, the heat generation in this study is established as the temperature on the wall of the tube which was 400 K. The turbulence model of this study used the k-epsilon model and the material of the tube was copper. For the boundary condition, the inlet was defined by velocity inlet, the outlet was defined by pressure outlet and the symmetry was established on four sides on right, left, top, and bottom. The solution method of this simulation used a scheme of SIMPLE with pressure as second order, momentum, and energy as second-order upwind.

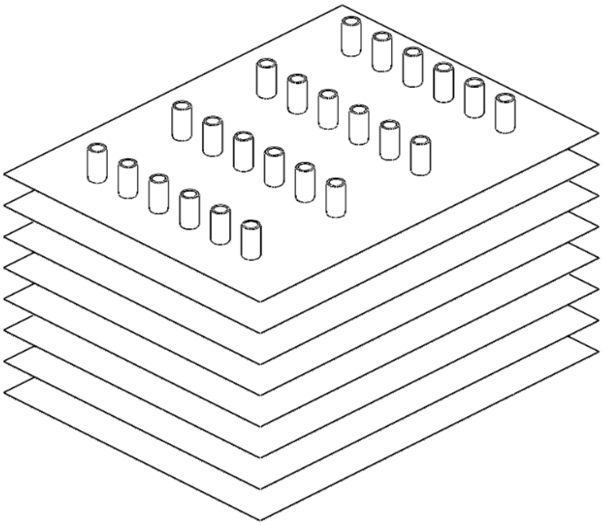

Figure 1. The Illustration of fin and tube heat exchanger without vortex generators.

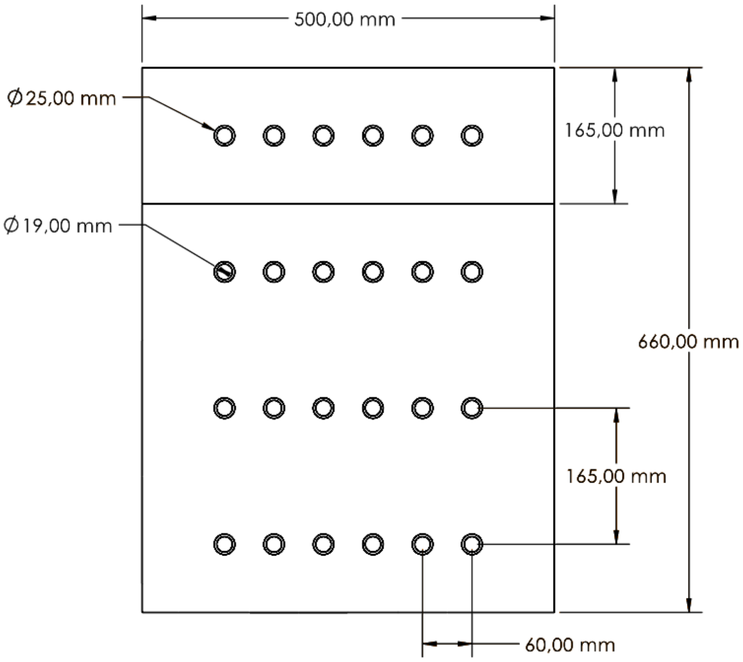

Figure 2. The Geometry Schematic of fin and tube heat exchanger.

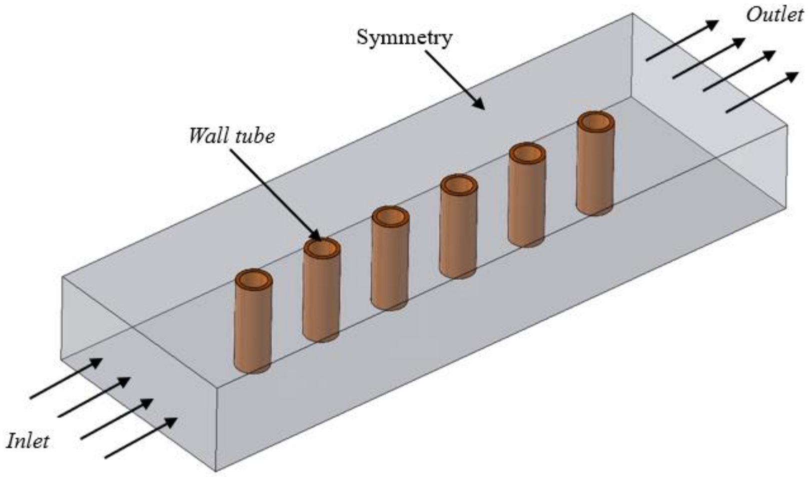

Figure 3. The computational domains for this study on fin and tube heat exchangers.

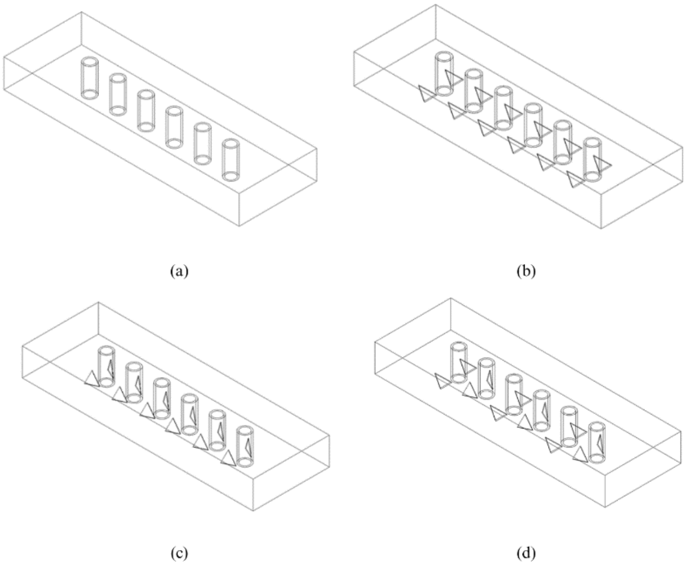

Figure 4. schematic of simulation domain of fin and tube heat exchanger for some models, (a) without VG, (b) Delta wing, (c) Delta Winglet, (d) Combination VG of Wing and Winglet.

3 Results and Discussions

This study uses the Nusselt number to represent heat transfer performance. Fig. 5 shows the simulation results, indicating an increase in the Nusselt number with each rise in the Reynolds number. The increase in Reynolds number enhances the Nusselt number depending on the case variation. [4]. This increase occurs due to the presence of a vortex generator, which can create longitudinal vortices that disrupt the main flow, reduce the wake region, and improve heat transfer. [4]. Fig. 5 demonstrates that the use of a vortex generator can enhance heat transfer performance.

The variation of the Reynolds number from 4000 to 8000, with intervals of 500, produced an average Nusselt number increase of 6.042% - 6.744% for the delta wing vortex generator, 8.450% - 12.075% for the delta winglet vortex generator, and 6.621% - 8.170% for the combination of delta wing and winglet vortex generators compared to the baseline. The overall average increase in Nusselt number for Reynolds numbers from 4000 to 8000, at 500 intervals compared to the baseline, was 6.249% for the delta wing vortex generator, 10.042% for the delta winglet vortex generator, and 6.594% for the combined delta wing and winglet vortex generator. The delta winglet vortex generator achieved higher Nusselt number values compared to both the delta wing vortex generator and the combined delta wing and winglet vortex generator. Therefore, it can be concluded that the delta winglet vortex generator enhances heat transfer more effectively, as it creates strong longitudinal vortices. [11].

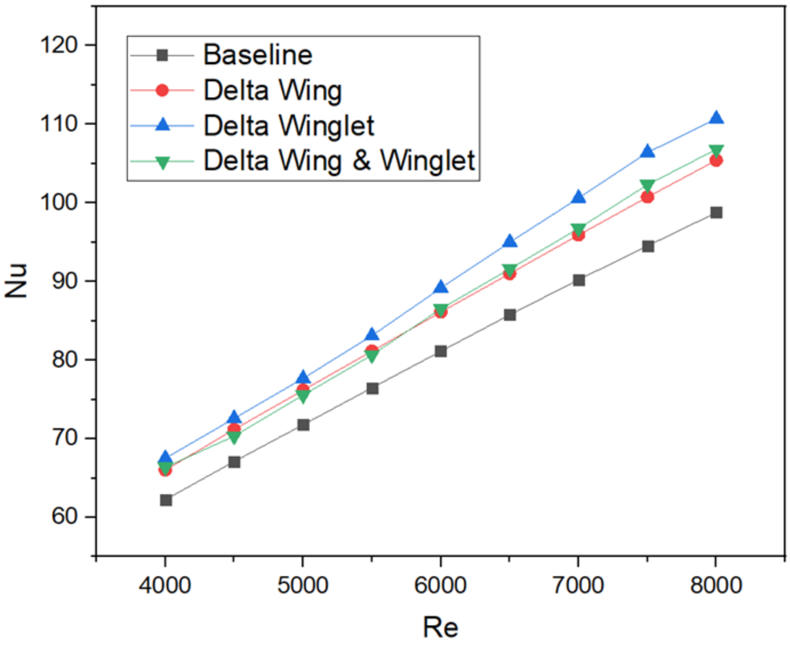

Figure 5. The effect of Nu (Nusselt Number) vs Reynold number (Re)

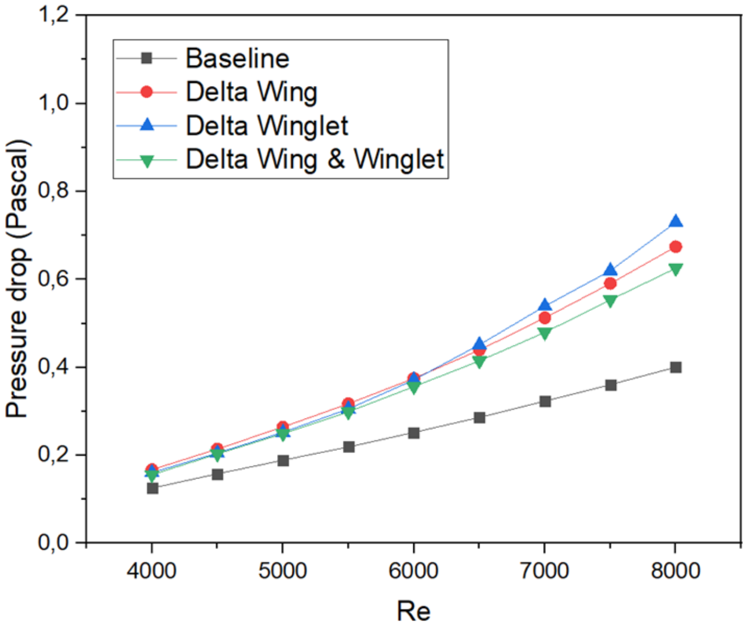

Figure 6. Effect of pressure drop vs Reynold's number

Fig. 6 shows that an increase in the Reynolds number leads to a rise in the pressure drop. This increase occurs because a higher Reynolds number enhances the frictional force between the fluid and the surface of the vortex generator, resulting in a higher pressure drop. [3]. The use of a vortex generator can improve heat transfer performance and also increase the pressure drop value. [11].

The average results from Fig. 6 show an increase in pressure drop for vortex generators with Reynolds number variations from 4000 to 8000, at intervals of 500, with increases of 33.55% - 68.32% for the delta wing vortex generator, 28.22% - 143.59% for the delta winglet vortex generator, and 24.34% - 56.18% for the combination of delta wing and winglet vortex generators, compared to the baseline. The overall average pressure drop increase from using vortex generators was 49.63% for the delta wing vortex generator, 65.04% for the delta winglet vortex generator, and 40.62% for the combined delta wing and winglet vortex generator, compared to the baseline. Therefore, it can be concluded that the delta winglet vortex generator produces the highest average pressure drop. This increase in pressure drop is caused by the resistance from fluid flow impacting the walls of the delta winglet vortex generator, and the larger surface area of the delta winglet vortex generator results in a higher pressure drop value. [12].

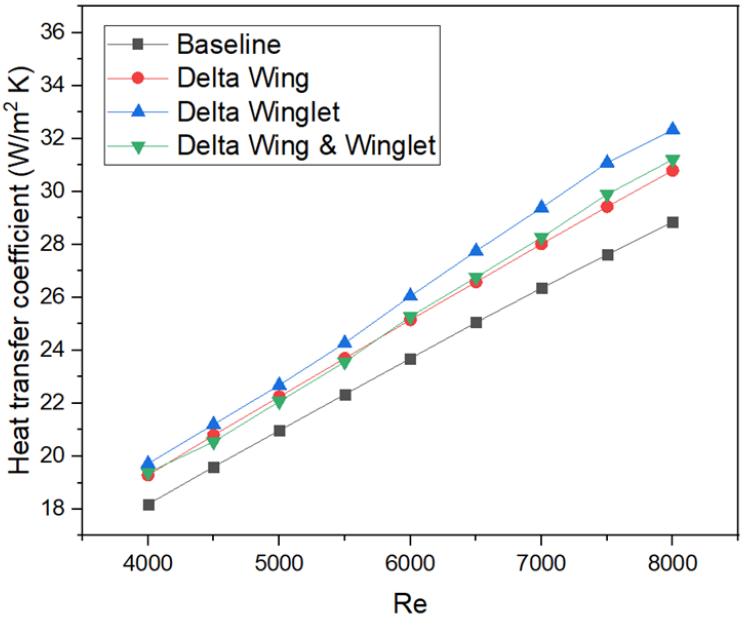

Figure 7. Effect of heat transfer coefficient vs Reynold number with difference of vortex generator

Fig. 7 shows that using a vortex generator can enhance the heat transfer coefficient as the Reynolds number increases. A higher Reynolds number improves heat transfer performance due to increased turbulence intensity and flow vorticity. [12]. Fig.7 illustrates the rise in the heat transfer coefficient for vortex generators with Reynolds number variations from 4000 to 8000 at 500 intervals, resulting in increases of 6.04%, 6.09%, 6.11%, 6.10%, 6.15%, 6.12%, 6.31%, 6.57%, and 6.74% for the delta wing vortex generator; 8.45%, 8.18%, 8.20%, 8.69%, 9.92%, 10.79%, 11.51%, 12.57%, and 12.07% for the delta winglet vortex generator; and 6.62%, 4.83%, 5.23%, 5.48%, 6.68%, 6.84%, 7.24%, 8.25%, and 8.17% for the combined delta wing and winglet vortex generator, compared to the baseline. The overall average increase in the heat transfer coefficient for Reynolds numbers from 4000 to 8000 at 500 intervals was 6.25% for the delta wing vortex generator, 10.04% for the delta winglet vortex generator, and 6.59% for the combined delta wing and winglet vortex generator, compared to the baseline.

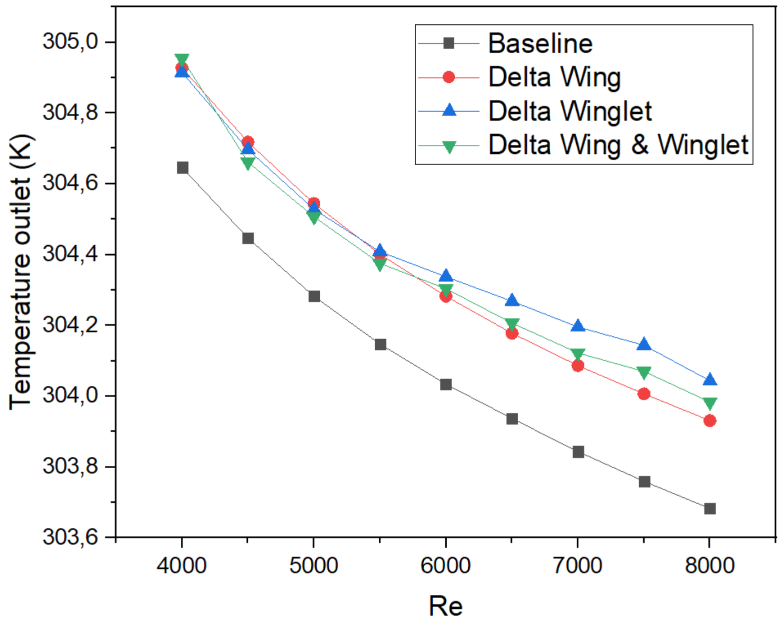

Figure 8. Temperature outlet distribution vs Reynold number with the difference of vortex generator.

The graph in Fig. 8 shows that with each increase in the Reynolds number, the outlet temperature decreases. It can be seen that the outlet temperature for Re 4000 with the delta wing vortex generator decreases by -0.33% compared to the outlet temperature at Re 8000. Similarly, the delta winglet vortex generator shows a temperature reduction of -0.29% from Re 4000 to Re 8000, and the combination of delta wing and winglet vortex generators also exhibits a temperature decrease of -0.32% from Re 4000 to Re 8000. The decrease in outlet temperature with higher Reynolds numbers is due to the high flow velocity, which limits effective heat absorption. Fig.8 also clearly shows that the use of vortex generators results in a higher outlet temperature than the baseline, due to the extensive contact of the fluid flow with the vortex generator surfaces, creating longitudinal vortices that enhance heat transfer performance. [4].

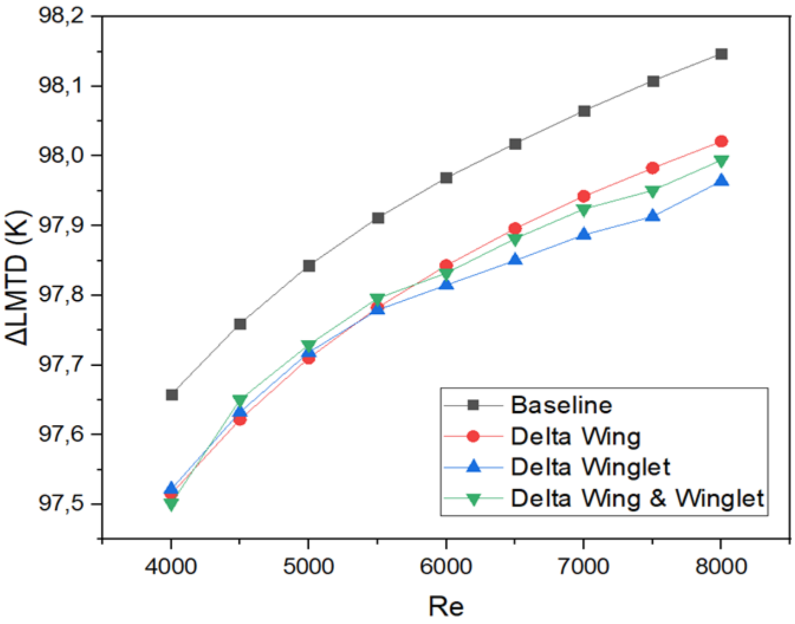

Figure 9. Effect of log mean temperature difference vs Reynold number with the difference of vortex generator

Fig. 9 shows that as the Reynolds number increases, the value of the logarithmic mean temperature difference (LMTD) also rises. This increase in LMTD indicates a greater amount of heat transfer, as the LMTD represents the average logarithmic difference between hot and cold temperatures at the outlet. [13]. The average increase in LMTD values for vortex generators from Re 4000 to Re 4500 up to Re 8000, at intervals of 500, is 0.11%, 0.20%, 0.27%, 0.34%, 0.39%, 0.44%, 0.48%, and 0.52% for the delta wing vortex generator; 0.11%, 0.20%, 0.26%, 0.30%, 0.34%, 0.37%, 0.40%, and 0.45% for the delta winglet vortex generator; and 0.15%, 0.23%, 0.30%, 0.34%, 0.39%, 0.43%, 0.46%, and 0.51% for the combination of delta wing and winglet.

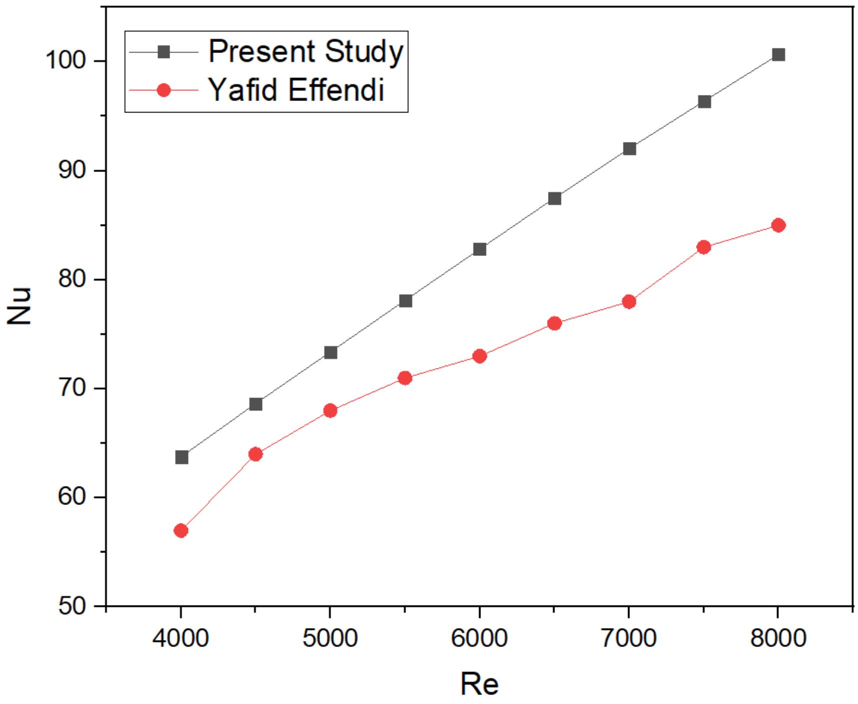

Figure 10. Comparison study for a correlation between Nusselt number vs Reynold number

In Fig. 10, the experiment conducted by Yafid Effendi will be used to validate the current study [12], ensuring the accuracy of the generated data. Validation will use the Nusselt number, as it is a dimensionless unit, along with a plain fin and tube heat exchanger and Reynolds numbers ranging from 4000 to 8000 in intervals of 500. Figure 4.34 shows a percentage difference of 13.14% between Yafid Efendi's study and the current study, likely due to methodological differences. Yafid Efendi's study used an experimental approach, while the current study employs a simulation method.

4 Conclusions

This study aims to improve the heat transfer performance of heat exchangers through additional vortex generators such as plain, wing, winglet, and a combination of wing and winglet vortex generators, which can be drawn from this paper. The summary of this study is as follows;

1. The use of a vortex generator as a principle can improve the heat transfer coefficient and Nusselt number by around 12% compared to without a vortex generator. For delta winglets, it can augment better than a delta winglet vortex generator.
2. The phenomenon of fluid flow, which affected the wake region behind the tube, was seen by pressure drop. The higher the pressure drop value, the more the primary fluid was mixed with the secondary fluid, which enhanced the heat transfer process.

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