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Influence of Staggered Tube Configuration on the Performance of Convection Heat Transfer of Cross-Flow Heat Exchanger

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***Abstract* - This study aims to analyze the influence of Reynolds number velocity and heating power on the staggered tube arrangement toward the thermo-hydraulic performance of an air-cooled cross-flow heat exchanger. This experimental study employed test air velocities varying from 4–28 m/s and three heating power variations of 20, 30, and 40 W. Measurements included pressure drop (ΔP), logarithmic mean temperature difference (ΔTlm), convective heat transfer coefficient (h), and Nusselt number (Nu). The measurement results indicate that the pressure drop increased significantly with increasing flow velocity, whereas the logarithmic mean temperature difference decreased. Meanwhile, the convective heat transfer coefficient and Nusselt number were found to increase along with the increase in Reynolds number.**

Keywords: heat exchanger, Reynolds number, Nusselt number, heat transfer coefficient.

I. INTRODUCTION

Heat exchangers (HEs) are important equipment in various industrial applications such as power plants, petrochemical processes, air conditioning systems, and the food industry. The efficient use of heat exchangers can save energy by up to 30–50%. The demand for HEs continues to increase along with the development of the manufacturing industry, with the shell-and-tube configuration becoming the primary choice due to its ease of fabrication and scalability [1], [2], [3], [4].

The performance of a heat exchanger is influenced by fluid velocity, tube diameter, tube arrangement (aligned/staggered), pitch ratio, and the number of tube rows. Tube bundle cross-flow depends on empirical correlations of the Nusselt number (Nu) and pressure drop (ΔP) [2], [3], [5], [6]. Tube banks are widely used in cross-flow heat exchangers, where the design depends on empirical correlations for pressure drop and heat transfer [3]. Tube bundle arrangements are generally classified into two types: aligned and staggered. The staggered tube arrangement is capable of producing a higher heat transfer coefficient, approximately 7% greater than the aligned tube arrangement [6].

In convective heat transfer, vortex flow plays an important role in accelerating the heat transfer process. In staggered tube arrangements, vortices are observed in every tube row, whereas in in-line tube arrangements, no vortex flow is found due to the wake zone [2]. In addition, increasing the fluid flow velocity also plays an important role in increasing the Reynolds number and Nusselt number, which ultimately enhances the heat transfer coefficient. Thus, the heat transfer rate increases as the fluid flow velocity increases [7]. In this study, the main focus is to examine the effects of variations in Reynolds number and heating power on the performance of a staggered tube arrangement in a cross-flow heat exchanger.

II. METHODOLOGY

2.1 Test Model

This study uses a heating element test model as a representation of a heated pipe subjected to disturbances from the pipe arrangement in the upstream section. The test model configuration is arranged in a staggered pattern as shown in Figure 1 below.

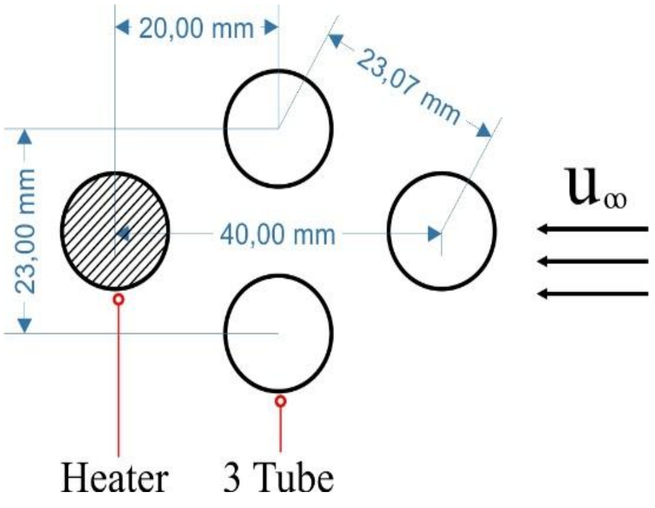

Figure 1: Test Model

2.2 Experimental Setup

This experimental study used an open-type wind tunnel as shown in Figure 2. The test apparatus has a duct cross-sectional area of 150 mm × 150 mm and a length of 1540 mm. The equipment is equipped with an air-driving fan as the working fluid source, with a maximum power of 1.5 kW. In this experimental setup, the maximum airflow rate is 2160 m³/h. Airflow velocity measurements were carried out using a pitot tube installed at the upstream section of the model. Meanwhile, static pressure measurements were taken using a pressure tap positioned on the lower surface of the test section.

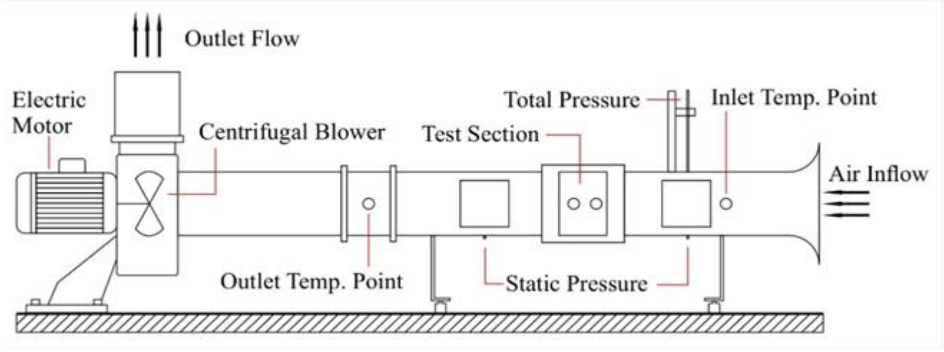

Figure 2: Experimental setup fan

III. RESULTS AND DISCUSSIONS

3.1 Pressure Drop

The pressure drop measurement results in the test section are presented in the plot in Figure 3. From this plot, it can be observed that the pressure loss characteristics of the tested configuration model generally increase with the rise in Reynolds number. For the tests conducted using three different heater power variations—20 W, 30 W, and 40 W—the results showed nearly identical values. No significant differences were found among the three heater power variations used. In short, it can be concluded from this experiment that changes in heater power do not have a sufficiently strong effect on the resulting pressure loss.

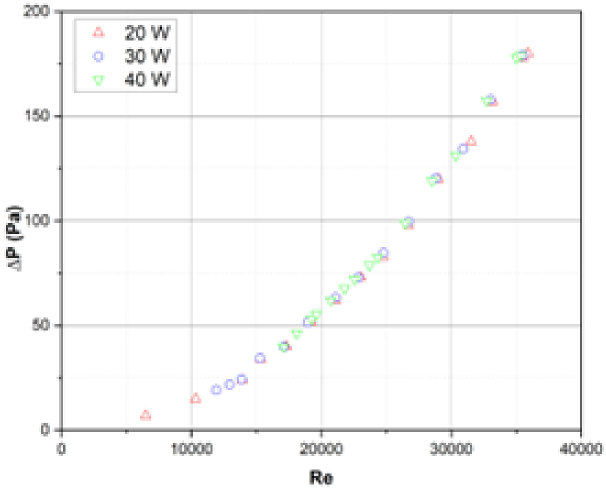

Figure 3: Pressure drop (ΔP) as a function of Reynolds number (Re)

3.2 Mean Effective Temperature difference

The results of the logarithmic mean temperature difference measurements for the configuration model tested here with three different heater power variations of 20 W, 30 W, and 40 W are shown in Figure 4. This plot presents the relationship between the temperature difference as a function of changes in the Reynolds number. From the plot, it can be seen that, in general, the logarithmic temperature differences for the three tests show similar trends. It is observed that all tests indicate a decrease in the average temperature difference with increasing Reynolds number during the experiments. For the three power levels tested in this study, higher heating power results in a greater logarithmic mean temperature difference compared to the other two lower power test conditions.

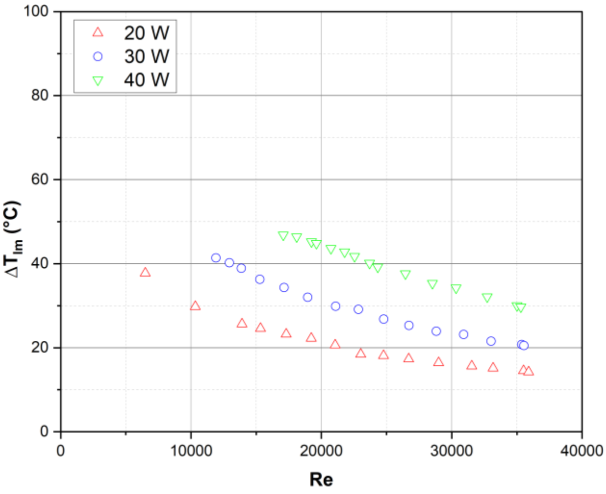

Figure 4: Mean effective temperature difference as a function of Reynolds Number

3.3 Coefficient of Covection and Nusselt Number

Figures 5 and 6 show the results of the convection coefficient and Nusselt number tests as a function of heating power for three Reynolds number tests. These plots show that the characteristics of the convection coefficient change slightly with increasing heating power. For the three Reynolds number variations tested, generally, high Reynolds numbers produce high convection coefficients. The Nusselt number plot, as shown in Figure 6, shows that increasing Reynolds number does not significantly affect the change in Nusselt number. It can be noted from this plot that higher Reynolds numbers produce higher Nusselt numbers, as shown in the plot.

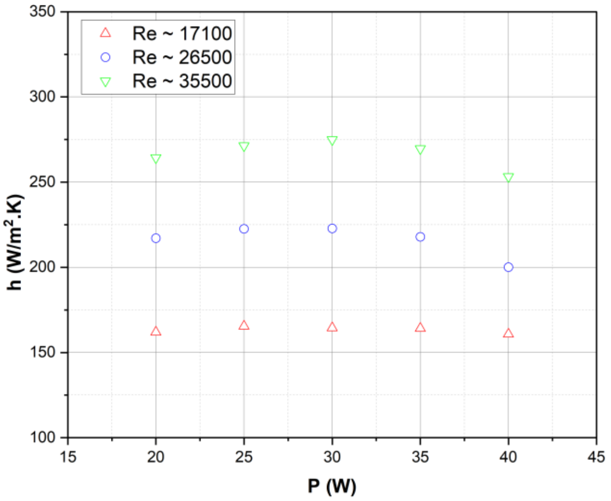

Figure 5: Coefficient of Convection (h) as a function of heater power

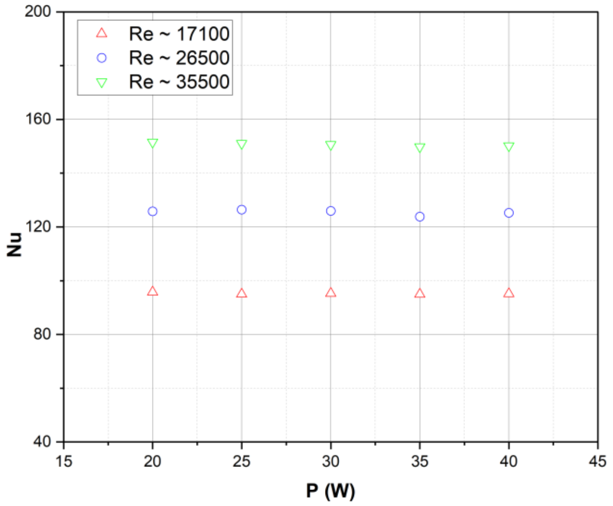

Figure 6: Nusselt Number (Nu) as a function of Heater Power

IV. CONCLUSION

Based on the measurement results in this study, several important results can be noted as follows: Pressure loss increases with increasing Reynolds number for all three values of heating power tested. Here, heating power does not significantly affect the resulting pressure drop difference. Likewise, a similar tendency for h and the Nu number increases with Re. However, increasing Re causes a decrease in the average logarithmic temperature difference in this test. Increasing heating power in this measurement does not significantly affect either the pressure drop or h and the Nu number.

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