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An Experimental Study on the use of Fins on Tubes In Shell-and-Tube Heat Exchangers To Improve Thermal Performance

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ABSTRACT

This research is to analyze the efficiency of the heat exchanger with the addition of fins in each tube. In order to see the efficiency of heat exchangers, this research was carried out through heat exchanger machine tests along with the collection of calculation data in the form of equations. This heat exchanger is in the form of shell and tube, which in the shell has eight passes, each pass has eight tubes and each tube has an additional number of fins, two, four and six. The flow of fluids used in heat exchanger research is through cross flow, where the flow of cold fluid will be channeled through a tube inside the shell that is blown by the blower where the speed is regulated to get a different mass rate, there will also be a heat transfer of cold fluid from the hot fluid distributed in the shell. Through the LPG combustion stage, hot fluid is produced for hot fluid. The cold fluid passing through the tube will receive heat from the hot fluid to the rotary dryer. After data calculation, heat exchangers were obtained with 2 fins per tube for an efficiency output of 57.9%, heat exchangers with 4 fins per tube with an output of 58.5%, heat exchangers with 6 fins per tube with an output of 61.4%.

KEYWORDS
Heat Exchanger, Shell and Tube, fin, mass rate

INTRODUCTION

Heat exchanger devices as instruments are designed to facilitate heat transfer from heat source to cold source (Marzouk et al., 2023; Thulukkanam, 2024; J. Wang et al., 2022, 2024; X. Wang et al., 2022). Usually, heat exchangers are made of plates as a limitation of two fluids, in anticipation of direct contact between the two (Dewi, 2022). Shell and tube heat exchanger is a type of heat exchanger machine that is often widely used for various ranges of temperature and operational operational pressures (Prajapati and Patel, 2020; Prajapati et al., 2024). For shell and tube construction, it consists of cylindrical tubes arranged in the shell. Shell and tube can be flowed with two different fluids, one fluid can be flowed inside the tube and one fluid flow can be flowed inside or outside the tube, but on the condition that the two fluids have a difference in temperature (Irwin and Rahmat, 2013). The advantages of shell and tube type heat exchangers are 1. The condensation or heat transfer process can be accommodated from the shell as well as the tube, 2. The pressure drop can be varied in line with the heat exchanger's capabilities, 3. Thermal stress is easy to press, 4. The selection of materials allows for variation, 5. In order to increase heat transfer, fins were added to the tube and 6. Maintenance is relatively easier because it allows installation and disassembly (Siagian, 2016).

A study conducted by Syah, et al (Syah, 2013) regarding the performance of shell and tube type heat exchangers regulating output temperature by utilizing parameters such as the use of kerosene, outlet temperature, total heat transfer coefficient, heat transfer rate, NTU (Number of Transfer Units), and efficiency. In the research conducted by Akbar, et al (2015), they discussed the design of shell and tube type heat exchanger condensers for the ORC

(Organic Rankine Cycle) system with the aim of finding the optimal fluid for use. Lebo, et al. (2015) conducted a more detailed study on the performance of heat exchangers in the induced draft fan drive system. They used various parameters such as heat transfer rate, actual average temperature difference (ΔTLMTD), overall heat transfer coefficient, pollution level, and NTU effectiveness method to analyze such heat exchangers. Therefore, the researcher wanted to conduct research on shell and tube heat exchangers by varying the number of fins (Ao et al., 2022; Harchaoui et al., 2025; Hassaan, 2022; Ji et al., 2024; Marzouk et al., 2023; Sohrabi et al., 2024).

The objectives of this study are to analyze the thermal performance of a shell-and-tube heat exchanger with the addition of fins (two, four, and six fins per tube) and to determine the effect of varying the number of fins on heat exchanger efficiency. Specifically, this study aims to calculate key parameters such as temperature difference, cold fluid heat rate, total heat transfer coefficient, cold fluid heat transfer coefficient, and overall heat exchanger efficiency under different cold fluid mass flow rates.

The benefits of this research are twofold. Theoretically, this study contributes to the body of knowledge in heat transfer engineering by providing experimental evidence on the relationship between the number of fins and heat exchanger efficiency, thereby enriching the understanding of finned tube heat exchangers in cross-flow configurations. Practically, the findings can serve as a reference for engineers and practitioners in designing more efficient shell-and-tube heat exchangers for industrial applications, such as rotary dryers and waste heat recovery systems, where optimizing thermal performance is crucial for energy savings and operational cost reduction.

METHOD

The research method applied by the researcher involves experiments using *heat exchanger* machines attached to *rotary dryers*, data collection, and data analysis using relevant equations to calculate heat *exchanger efficiency*. The test equipment used is a type of *heat exchanger* in the form of *a shell* and *tube*. In the *shell structure*, there are 8 passes, and each of them is equipped with eight tubes. In addition, each tube has an additional fin numbering two, four, or six. The details of the equipment and its installation are described in Figure 1.

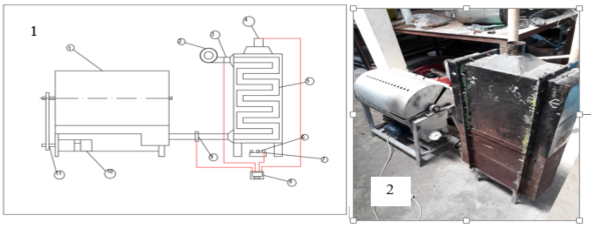

Figure 1. 1) Schematic Installation Research and 2) Heat Exchanger assembled Rotary Dryer

Source: Author's own documentation and design (2025)

In order to evaluate the stages of heat transfer in *heat exchanger* Based on the total heat transfer coefficient (U), there are 2 common methods, namely LMTD and NTU. The heat transfer stage is when two objects of different temperatures meet, where heat is transferred from a high-temperature object to a low-temperature object naturally. Heat transfer can occur through three main mechanisms: conduction, convection, and radiation (Ratnawati and Salim 2018). In this context, we will talk about conduction and convection.

Use calculations *mass flow rate* Cold fluids theorize heat equilibrium, where the sound of heat equilibrium, namely the heat received by the fluid, is equal to the heat reception of other fluids conditioned by different temperatures. In equation 1, namely the equation of heat equilibrium (Cengel, 2013).

$$\dot{Q}_{lepas} = \dot{Q}_{terima}$$

$$\dot{m}_h . Cp_h . \Delta T_h = \dot{m}_c . Cp_c . \Delta T_c$$

Calculation of the total heat rate coefficient (Cengel, 2013):

$$U = \frac{1}{\frac{1}{h_h} + \frac{\ln (R_o + R_i)}{2\pi k L} + \frac{1}{h_c}} \qquad (2)$$

Reynolds numerals calculation (Cengel, 2013):

$$Re = \frac{\rho V D}{\mu} = \frac{VD}{v} \qquad (3)$$

Nusselt numeral calculation (Cengel, 2013):

$$Nu = 0.023\ Re^{0.8} Pr^{0.4} \qquad (4)$$

An equation of 5 can determine the number of heat transfer coefficients (J.P Holman, 2010):

$$h = \frac{Nu\ K}{D} \qquad (5)$$

Methoded *Effectiveness*-NTU. Use the *effectiveness*-NTU is related to effectiveness, which is equation 6 for the calculation of effectiveness (J.P Holman, 2010):

$$\varepsilon = \frac{\dot{Q}_{aktual}}{\dot{Q}_{maks}} \qquad (6)$$

When the actual heat rate figure can be calculated (J.P Holman, 2010):

$$\dot{Q}_{aktual} = \dot{m} \text{ x } Cp \text{ x } (T_{in} - T_{out}) \qquad (7)$$

Also for the maximum heat transfer rate is equal to 8 (J.P Holman, 2010):

$$\dot{Q}_{maks} = C_{min} (T_{h,\, in} - T_{c,\, in}) \qquad (8)$$

if the result of Cc is greater than Ch, then the equation of 9 (J.P Holman, 2010):

$$C_{min} = C_h = \dot{m}_h \text{ x } Cp_h \qquad (9)$$

If the output Cc is greater than Ch, the equation is 10 (J.P Holman, 2010):

$$C_{min} = C_c = \dot{m}_c \text{ x } Cp_c \qquad (10)$$

Setting the output ratio C. Using equation 11 used to set the ratio C(J.P Holman, 2010):

$$C = \frac{C_{min}}{C_{max}} \qquad (11)$$

In order to determine the NTU number through an analysis of the equation of 12 (J.P Holman, 2010):

$$NTU = \frac{1}{C} \ln \{1 + C \ln (1 - \varepsilon)\} \qquad (12)$$

Use the determination of the surface area of the pipe/tube blanket without fins/*end* with equation 13 (Frank P. Incropera, 2005):

$$A_{unfin} = \pi D L \qquad (13)$$

About This case is accompanied by a circle/ring shaped fin. In the determination of the surface area *circular fin* equation 14 (Frank P. Incropera, 2005):

$$A_{fin} = 2\pi\,(r_2^2 - r_1^2) + 2\,\pi\,r_2\,t \qquad (14)$$

Efficiency *heat exchanger* It can be calculated by equation 15. (Frank P. Incropera, 2005):

$$\eta = \frac{Qc}{Qh} \qquad (15)$$

RESULT AND DISCUSSION

The research was carried out by testing the machine using a heat exchanger, which is in the form of a shell and tube. In the shell there are 8 passes, each pass is a tube, besides that each tube has an additional fin totaling two, four, six. Fins are attached to each circular tube for data retrieval for the calculation of heat exchanger efficiency.

Temperature Change

After doing the calculation, where a comparison was made with Figure 2 showed a decrease during the heat exchanger test using fins 2, 4 and 6. Where from the test at the cold fluid mass rate of 0.021 kg/s when testing the heat exchanger for fins 2, 4 and 6 became the maximum point because at the time of testing with the addition of the cold fluid mass flow rate the heat transfer was not optimal.

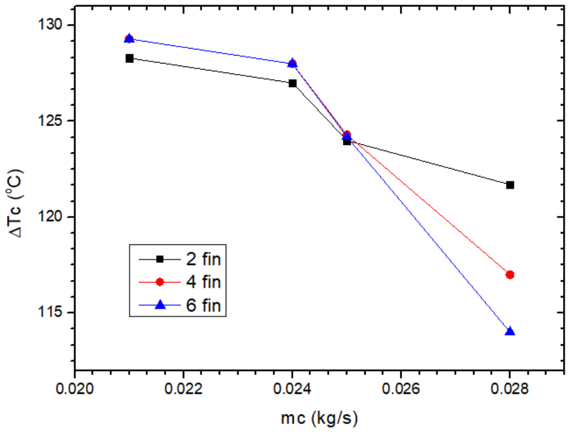

Figure 2. Temperature Difference (ΔTc) – Mass Rate of Cold Fluid (ṁc)

Source: Author's own calculation and analysis (2025)

Cold Fluid Heat Rate

After doing the calculation, where a comparison was made with the figure 3 of the increase during the heat exchanger test using fins 2, 4 and 6. Where from the test during the heat exchanger test for fin 2, 4, 6 in the test with a cold fluid mass rate of 0.028 kg/s is the maximum point because at the time of addition the cold fluid mass rate is directly proportional to the heat rate of the cold fluid. Theoretically it is also shown that the mass rate of cold fluid is directly proportional to the heat rate of cold fluid. For a finite heat exchanger with a number of 6 which produces a greater thermal rate of cold fluid (qc) with a value of 3388.2 W than a heat exchanger with fins 2 and 4.

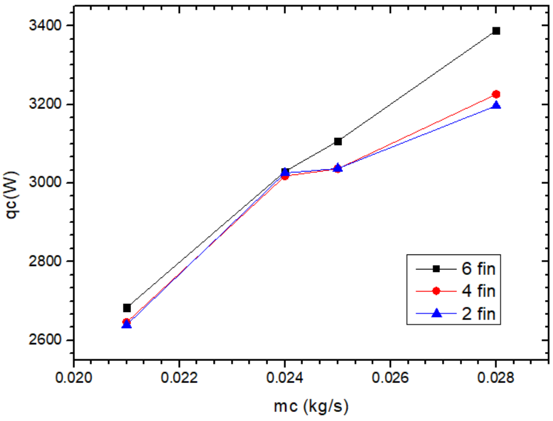

Figure 3. Cold Fluid Heat Rate ("q" ̇c) – Cold Fluid Mass Rate (ṁc)
Source: Author's own calculation and analysis (2025)

Figure 2 of the mass rate of the cold fluid – the temperature difference compared to the figure 3 of the mass rate of the cold fluid – the rate of heat is very inversely proportional to the theoretical, where the result of the temperature of the cold fluid is more dominant than the change in temperature of the cold fluid.

Total Heat Transfer Coefficient

After doing the calculation, where a comparison is made shown in figure 4. Judging from figure 4, it shows an increase during the heat exchanger test using fins 2, 4 and 6, where for the heat exchanger test the cold fluid mass (ṁc) is 0.028 kg/s maximum point, in the heat exchanger with fin 4 the total heat transfer coefficient (U) results are equal to 6,305 W/m2K, the heat exchanger with fin 6 results in the total heat transfer coefficient (U) is equal to 5,380 W/m2K and when the heat exchanger uses fin 2 produces a heat transfer coefficient The total (U) value of 7,648 W/m2K is greater than the heat exchanger with fins 4 and 6, because in the calculation of the equation of the number of fins, the total heat transfer coefficient produced is large.

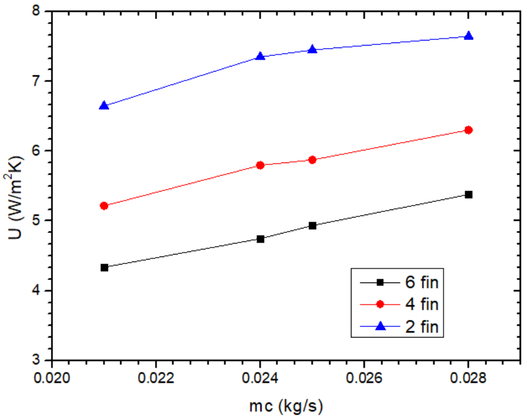

Figure 4. Total Heat Transfer Coefficient (U) – Mass Rate of Cold Fluid (ṁc)
Source: Author's own calculation and analysis (2025)

Heat Transfer Coefficient of Cold Fluids

After doing the calculation, where a comparison is made shown in figure 5 of the increase during the heat exchanger test using fins 2, 4 and 6, where for the heat exchanger test at the cold fluid mass rate of 0.028 kg/s maximum point. The output of the heat transfer of cold fluids in a heat exchanger with fin 4 is 347.7 W/m2K, the result for the heat transfer of cold fluid when a heat exchanger with fin 2 has a value of 350.6 W/m2K and the result of a heat exchanger using fin 6 produces a heat transfer coefficient of cold fluid with a value of 350.7 W/m2K greater than that of heat exchangers with fins 2 and 4.

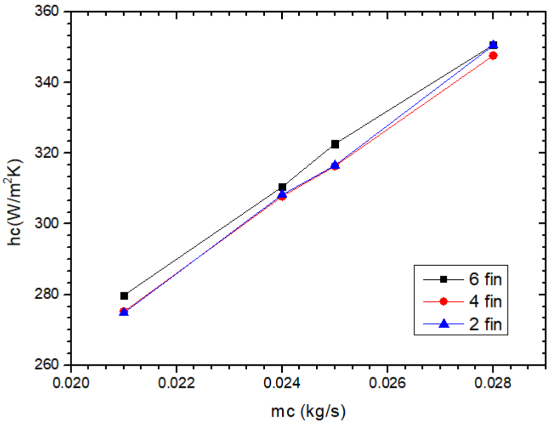

Figure 5. Cold Fluid Heat Transfer Coefficient (hc) – Cold Fluid Mass Rate (ṁc)

Source: Author's own calculation and analysis (2025)

Heat Exchanger Efficiency

After doing the calculation, where the comparison shown in figure 6 is carried out shows an increase during the heat exchanger test using fins 2, 4 and 6 where for the heat exchanger test when the cold fluid mass rate is 0.028 kg/s maximum point. For the heat exchanger fin 2, the efficiency is 57.9%, the efficiency of the heat exchanger fin 4 is 58.5%, as well as the result of heat exchanger fin 6, which is 61.4%. In heat exchangers that use fins 2 and 4 are smaller than heat exchangers with fins 6.

In the test, it was carried out using a heat exchanger in the form of a heat exchanger with the addition of 2 fins and 4 fins, where the shape of the fin in this test was a rectangle attached to each tube. The results obtained during testing in the heat exchanger with the addition of 4 fins. The output obtained was 78.9 % in the heat exchanger experiment using 4 fins at the mass rate of the cold fluid 0.026 kg/s. For the experiment when using a heat exchanger using 2 fins, the result was 55.95%. The efficiency of both experiments with different ones results in the highest efficiency on heat exchangers with 4 fins. With the addition of a large yield heat exchanger efficiency fin

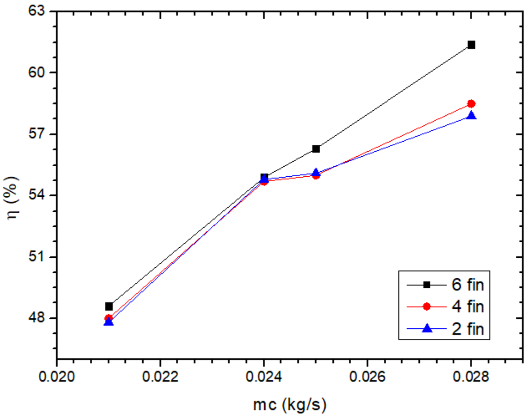

Figure 6. Heat Exchanger Efficiency (η) – Cold Fluid Mass Rate (ṁc)

Source: Author's own calculation and analysis (2025)

CONCLUSION

From the test results for the data collection of shell and tube type heat exchangers with 8 passes where for each 1 pass there are 8 tubes and 1 tube there are additional fins totaling 2, 4 and 6. The calculation results obtained in the heat exchanger test using 2 fins resulted in the optimum heat exchanger efficiency of 57.9% at the time of testing with a cold fluid mass rate of 0.028%. From the calculation on the heat exchanger using 4 fins, the optimum heat exchanger efficiency was 58.5% at the time of testing the cold fluid mass rate of 0.028%. From the calculation on the heat exchanger using 6 fins, the optimum efficiency was 61.4% at the time of testing the cold fluid mass rate of 0.028%. From the tests carried out and calculations to get efficiency results, that with a large number of fins used in the heat exchanger, it will result in a high efficiency of the heat exchanger. It was proven in this test that the heat exchanger at the time of the sum of 6 fins obtained high efficiency. It is recommended that future research explore the use of different fin geometries (e.g., spiral or wavy fins) rather than only varying the number of rectangular fins, as well as investigate the effect of different fin materials on thermal performance. Additionally, further studies should consider varying the hot fluid mass flow rate and inlet temperature to obtain a more comprehensive understanding of heat transfer characteristics. Practically, for industrial applications, using six fins per tube is suggested to achieve optimal heat exchanger efficiency, particularly in rotary dryer systems where energy efficiency is critical.

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