

Effectiveness Test of a Cross-Flow Air Cooler Heat Exchanger (Steady State)

¹*Muchammad, ²Muhammad Tafarel Firjatullah, ³Budi Setiyana

^{1,2,3}Mechanical Engineering Department, Faculty of Engineering, Diponegoro University, Jl. Prof. H. Soedarto, SH, Tembalang-Semarang 50275, Indonesia

*Corresponding Author's E-mail: muchammad5373@gmail.com

Abstract - Heat exchangers are widely used in various industrial installations, including boilers, condensers, coolers, and cooling towers. In vehicles, the radiator essentially functions as a heat exchanger. The purpose of heat transfer in industrial processes includes heating or cooling fluids to achieve specific heat levels that meet the requirements for subsequent processes making it essential to conduct research to develop more efficient heat exchangers. This study aims to determine the effectiveness of an air cooler heat exchanger with a constant hot water temperature (steady state) at maximum, and the impact of varying pump and fan flow rates on its performance. The research method was experimental, using an air cooler heat exchanger with water flow rates of 0 L/min, 2.5 L/min, and 5 L/min, and air speeds of 1.8 m/s, 2.7 m/s, and 3.6 m/s. Observations included monitoring the air temperature exiting the fan, controlling the time until steady state conditions were achieved. The experimental results showed that the best effectiveness was 0,608696, and the best efficiency was 96%. These optimal results were obtained when the air cooler heat exchanger was operated with a water flow rate of 5 L/min and an air speed of 1.8 m/s. This operational condition is considered the best because the high water flow rate increases the cooling capacity, and the low air speed provides sufficient contact time between the air and the heat exchanger surface.

Keywords: efficiency, effectiveness, air velocity, water flow rate, heat exchanger.

I. INTRODUCTION

Heat exchanger is widely used in various industrial installations, including boilers, condensers, coolers, and cooling towers. (Roetzel *et al.*, 2020). In vehicles, the radiator essentially functions as a heat exchanger. The purpose of heat transfer in industrial processes includes heating or cooling fluids to reach a specific temperature that meets the requirements for the next process and to change the state

(phase) of the fluid: distillation, evaporation, condensation, and so on. (Amrozi *et al.*, 2023).

The common types of heat exchangers include shell and tube heat exchangers, plate heat exchangers, and finned heat exchangers. (Maghrabie *et al.*, 2021). Finned heat exchangers have the advantage of high heat transfer efficiency and a compact design, but they are susceptible to fin damage, which can affect performance. (Blecich *et al.*, 2021). Plate heat exchangers have the advantage of being small in size and easy to maintain, but they are susceptible to corrosion and are not suitable for high-pressure applications. (Zheng *et al.*, 2021). On the other hand, shell and tube heat exchangers are capable of handling high pressure and large temperature differences, but their manufacturing and installation costs tend to be high. (Kallannavar *et al.*, 2020). The purpose of the research is to improve the efficiency and performance of heat exchangers by considering these factors and developing more effective and economical solutions. (Irawan *et al.*, 2020).

Based on the flow type, heat exchangers have three flow patterns used in different construction types: parallel flow, counter flow, and cross flow. In parallel flow, both fluid streams flow in the same direction. In counter flow, the fluid streams flow in opposite directions, while in cross flow, the fluid streams flow perpendicular to each other. (Irawan *et al.*, 2020).

An ACHE (Air Cooler Heat Exchanger) consists of one or more finned tube groups (also known as tube bundles) with air blown by one or more fans. Multiple fans may be used to blow air, facilitating heat exchange with the tubes in the bundle, through which a higher-temperature fluid flows. (Ikhsan Kamil & Agustina Sari, 2023). This discussion specifically focuses on energy-efficient air coolers that also require minimal space for placement. The main function of an air cooler is not to cool the room but to provide cooling for the room (Rohito *et al.*, 2019).

Current cooling technologies are increasingly utilized to improve living standards. Common uses include food preservation and room cooling. Air coolers available on the

market are priced between 1.3 million to 1.7 million rupiah, with a power consumption of 220-240 V and 100 W, and dimensions of 360 x 300 x 760 mm. Many air coolers on the market are relatively large, making them non-portable, and their power requirements are also quite high. (Rohito *et al.*, 2019).

Common room cooling devices used today often rely on substances that are less environmentally friendly, as they can damage the ozone layer and incur high operational and maintenance costs. The environmental damage and operational expenses can be minimized with a new, more eco-friendly and economical cooling device. (Fakhri *et al.*, 2022). Air coolers use water as the cooling medium, where the cold vapor produced is blown out by a fan to generate cool air. In contrast, if a fan is used in a hot room, it will only circulate the hot air. Therefore, air coolers are highly effective for cooling rooms, saving electricity, being environmentally friendly, and not requiring much space. (Rohito *et al.*, 2019).

This research is also relevant to the sustainability of heat exchanger systems, with a focus on optimizing energy use and resource management. By identifying optimal parameters for controlling the temperature of the cold fluid in air cooler heat exchanger systems, this study aims to provide new insights that can be implemented to enhance the performance and efficiency of cooling systems. Additionally, a better understanding of these dynamics will support technological innovation in creating more efficient and sustainable solutions for temperature control across various industrial sectors.

II. RESEARCH OBJECT

2.1 Heat Exchanger

A heat exchanger is a device used for the process of transferring heat between fluids with different temperatures, or for transferring heat from a hot fluid to a cold fluid. The heat transfer occurring within the heat exchanger happens through convection and conduction without mixing the two fluids, due to the presence of a separator. (Yuniarti *et al.*, 2022).

2.2 Air Cooler Heat exchanger

An air cooler heat exchanger is a pressurized vessel that cools the fluid circulating inside finned tubes by forcing the surrounding air to pass over the outer surface of the tubes. A common example of an air-cooled heat exchanger is a car radiator. (Aliver, 2013). An ACHE (Air Cooler Heat Exchanger) consists of one or more groups of finned tubes (also known as tube bundles) with air blown by one or more fans. (Ikhsan Kamil & Agustina Sari, 2023).



Figure 1: Air Cooler Heat Exchanger

In an air cooler heat exchanger, several components are assembled into a single unit. The components are listed in Table 1.

Table 1: Components of an air cooler heat exchanger

No	Components of an air cooler heat exchanger
1.	Part water storage tank on
2.	Part water storage tank lower
3.	Fan
4.	Pump
5.	Inline Pipe
6.	Switch on / off

2.3 Effectiveness (ϵ)

Effectiveness displacement hot a *heat exchanger* device is the ratio of the heat transfer rate (Q) to the value rate displacement hot maximum obtained from calculation (Q_{max}), follows is Equation (1) is used For count effectiveness :

$$\epsilon = \frac{Q}{Q_{max}} \quad (1)$$

Information:

ϵ = Effectiveness

Q = Heat transfer rate (W)

Q_{max} = Maximum heat transfer rate (W)

2.3.1 Calculation of Heat Transfer Rate (Q)

In knowing How many big displacement heat in the fluid can calculated with use Equation (2) as following.

$$Q = \dot{m} \times C_p \times \Delta T \quad (2)$$

Information:

Q = Heat transfer rate (Watts)

C_p = Heat capacity of the fluid (W/kg.K)

ΔT = Difference temperature fluid with temperature environment (K)

2.3.2 Calculation rate displacement hot actual (Q_{act})

Transfer rate hot actual is heat released by the fluid hot or that is absorbed by the fluid cold, that can be calculated with The equations in (3) and (4) are as follows:

$$Q_{act} = C_h \cdot (T_{h1} - T_{h2}) \quad (3)$$

$$Q_{act} = C_c \cdot (T_{c2} - T_{c1}) \quad (4)$$

Information:

Q_{act} = Displacement rate hot actual (W)

C_h = Displacement rate hot fluid heat (W/K)

C_c = Displacement rate cold fluid cold (W/K)

2.3.3 Calculation of Maximum Heat Transfer Rate (Q_{max})

On displacement hot maximum in fluid can calculated use Equation (5) as following.

$$Q_{max} = C_{min} (T_{hi} - T_{ci}) \quad (5)$$

Information:

Q_{max} = Maximum heat transfer rate (W)

C_{min} = Smallest value between Ch and Cc values (W/K)

T_{h,i} = Temperature of the hot fluid entering the heat exchanger (K)

T_{h,o} = Temperature of the cold fluid entering the heat exchanger (K)

2.4 Efficiency (η)

Efficiency thermal (η) heat exchanger as ratio transferred heat actual with the total power used For move hot . Efficiency this is often the case too linked with mark

effectiveness (ε), which is defined as ratio between transferred heat actual with hot maximum possible transferred (Moran, 2018). In calculating efficiency in Equation (6) as following.

$$\eta = \frac{Q_{act}}{P} \quad (6)$$

Information:

η = Efficiency heat exchanger (%)

Q_{act} = Actual heat (Joule)

P = Power (Watts)

2.5 Data Collection

Data collection begins with manual and real-time recording for 40 minutes, conducted in a steady-state condition (maintaining a constant water temperature). The tests involve varying the fan air speed and water flow rate from the pump. The variations in fan air speed include 100% or 3.37 m/s, 75% or 2.5 m/s, and 50% or 1.67 m/s. The variations in water flow rate include 100% or 5 liters/min, 50% or 2.5 liters/min, and 0% or 0 liters (no water flow).

After data collection, the data is analyzed to calculate the effectiveness of the device over time.

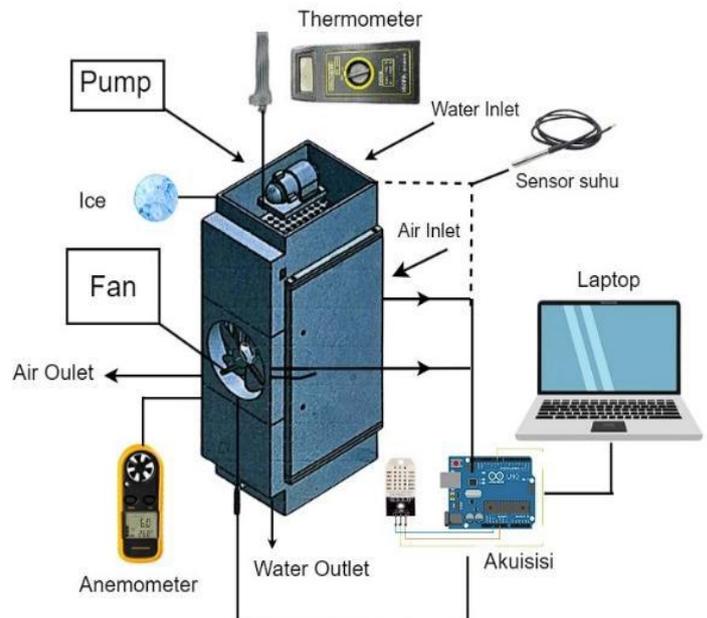


Figure 2: Data Collection Scheme

III. RESULTS AND DISCUSSION

3.1 Effectiveness (ϵ)

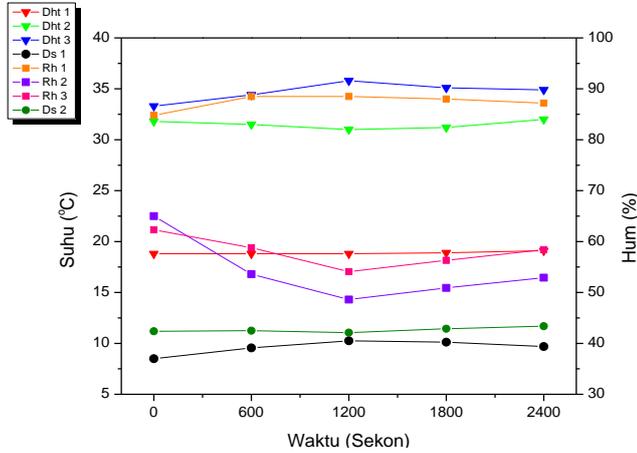


Figure 3: Chart effectiveness (ϵ) against time at variations in water flow of 5 liters/minute

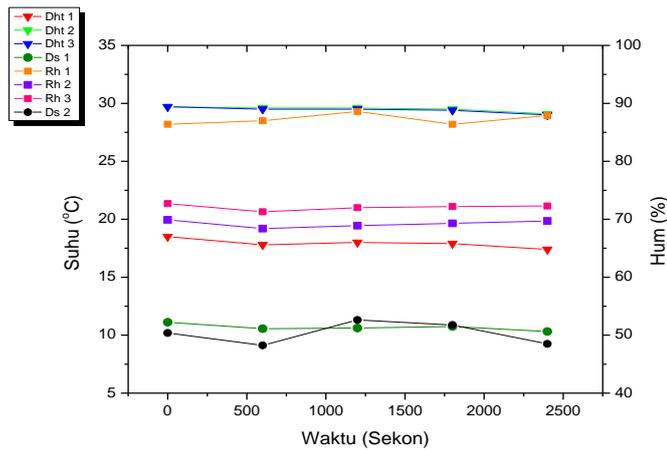


Figure 4: Chart effectiveness (ϵ) against time at variations in water discharge of 2.5 liters/ minute

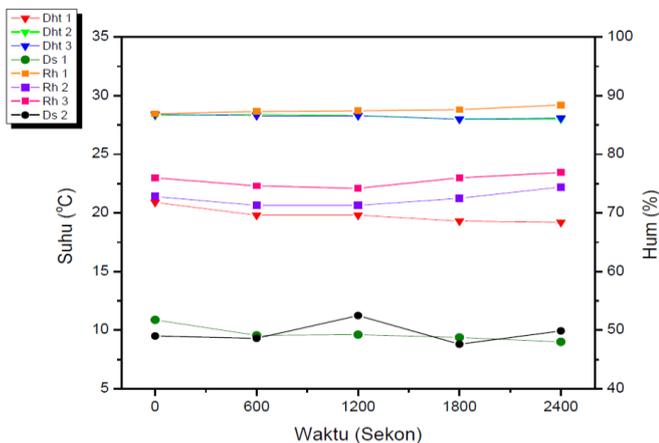


Figure 5: Graph of effectiveness (ϵ) against time for variations in water flow of 0 liters

The effect of water flow rate is evident from each test graph. In the graph showing a water flow rate of 5 liters/min, effectiveness is higher compared to 2.5 liters/min. However, the water flow rate of 0 liters has the highest effectiveness compared to the others, indicating that water flow rate impacts effectiveness results. Additionally, not only the water flow rate but also the air speed of the fan affects the effectiveness results. In each effectiveness graph, an air speed of 1.67 m/s shows superior effectiveness and stability compared to the maximum speed of 3.37 m/s.

3.2 Calculation results effectiveness(ϵ)

Effectiveness is calculated by determining the average temperature of the cold fluid at a constant (steady-state) condition in the air cooler. The effectiveness is derived from the heat exchanged between the water and the air. The results of the effectiveness calculation for the air cooler heat exchanger, using the average temperature, are shown in Table 2 below.

Table 2: The results of the test data calculations to obtain effectiveness results

Speed Flow		Q	Qmax	ϵ
Water	Air			
1 L/ 12 S	100 (3,37 m/s)	831,197	2307,87	0,36
	75 (2,5 m/s)	1643,484	2826,793	0,58
	50 (1,67 m/s)	1836,92	3017,798	0,608
1 L/ 24 S	100 (3,37 m/s)	1211,528	2449,111	0,49
	75 (2,5 m/s)	1400,097	2512,323	0,557
	50 (1,67 m/s)	1541,474	2542,774	0,606
0%	100 (3,37 m/s)	1083,466	2226,981	0,486
	75 (2,5 m/s)	1353,447	2576,755	0,52
	50 (1,67 m/s)	1126,08	2396,195	0,469

Based on the data presented in Table 2 regarding the effectiveness calculations, it can be concluded that the best effectiveness for the air cooler heat exchanger is achieved with a value of 0.608. This value is obtained when operating with a water flow rate of 5 L/min and an air speed of 1.67 m/s.

3.3 Calculation results efficiency(η)

Efficiency calculation requires determining the actual heat transfer rate compared to the power consumed by the pump, fan, and cooler in the air cooler heat exchanger. The results of the thermal efficiency (η) calculations are provided. The efficiency results for each variation can be seen in Table 2 below.

Table 3: Calculation results efficiency every variation

Speed Flow		Qact (watt)	Power (watt)	Efficiency (%)
Water	Air			
1 L/12 S	100 (3,37 m/s)	831,2	1.906,17	43
	75 (2,5 m/s)	1.643,5	1.899,98	86
	50 (1,67 m/s)	1.836,921	1.893,71	96
1 L/24 S	100 (3,37 m/s)	1.211,529	1.870,17	64
	75 (2,5 m/s)	1.400,097	1.870,17	75
	50 (1,67 m/s)	1.541,475	1.857,71	83
0	100 (3,37 m/s)	1.083,467	1.834,17	59
	75 (2,5 m/s)	1.353,448	1.827,98	74
	50 (1,67 m/s)	1.126,081	1.821,71	62

Based on the data presented in Table 3 regarding the efficiency calculations, the best efficiency for the air cooler heat exchanger is 96%. This value is achieved when operating with a water flow rate of 5 L/min and an air speed of 1.67 m/s.

IV. CONCLUSION

Based on results from testing and analysis on the air cooler which was carried out transiently, the following are the results:

1. The best effectiveness for the air cooler heat exchanger is 0.608, achieved when operating with a water flow rate of 5 L/min and an air speed of 1.67 m/s. Similarly, the best efficiency for the air cooler heat exchanger is 96%, also achieved with the same operating conditions of a water flow rate of 5 L/min and an air speed of 1.67 m/s.
2. The operational condition with a water flow rate of 5 L/min and an air speed of 1.67 m/s is considered the best because the large amount of water flowing through the heat exchanger increases the cooling capacity, and the low air speed provides sufficient contact time between the air and the surface of the heat exchanger.

REFERENCES

- [1] W. Roetzel, X. Luo, and D. Chen, "Chapter 1 - Heat exchangers and their networks: A state-of-the-art survey," W. Roetzel, X. Luo, and D. B. T.-D. and O. of H. E. and their N. Chen, Eds. *Academic Press*, 2020, pp. 1–12.
- [2] R. R. Amrozi, S. Udjiana, and Y. Yuliman, "Evaluasi Kinerja Heat Exchanger Pada Gas Cooler Unit Co2 Liquid Plant," *DISTILAT J. Teknol. Separasi*, vol. 8, no. 1, pp. 111–117, 2023, doi: 10.33795/distilat.v8i1.299.
- [3] H. M. Maghrabie *et al.*, "Intensification of heat exchanger performance utilizing nanofluids," *Int. J. Thermofluids*, vol. 10, 2021, doi: 10.1016/j.ijft.2021.100071.

- [4] P. Blecich, A. Trp, and K. Lenić, "Thermal performance analysis of fin-and-tube heat exchangers operating with airflow nonuniformity," *Int. J. Therm. Sci.*, vol. 164, no. January, 2021, doi: 10.1016/j.ijthermalsci.2021.106887.
- [5] D. Zheng, J. Yang, J. Wang, S. Kabelac, and B. Sundén, "Analyses of thermal performance and pressure drop in a plate heat exchanger filled with ferrofluids under a magnetic field," *Fuel*, vol. 293, no. November 2020, pp. 1–9, 2021, doi: 10.1016/j.fuel.2021.120432.
- [6] S. Kallannavar, S. Mashyal, and M. Rajangale, "Effect of tube layout on the performance of shell and tube heat Exchangers," *Mater. Today Proc.*, vol. 27, pp. 263–267, 2020, doi: 10.1016/j.matpr.2019.10.151.
- [7] D. Irawan, M. Wibowo, and Z. Anggara, "Pengaruh Jumlah Tube dan Baffles Terhadap Efektivitas Shell and Tube Heat Exchanger," *Semin. Nas. Penelit. dan Pengabd. Kpd. Masy. Univ. Muhammadiyah Metro Indones.*, vol. 2, pp. 254–264, 2020.
- [8] M. Ikhsan Kamil and D. Agustina Sari, "Komparasi Desain Alat Penukar Panas Tipe Air-Cooled," *J. Teknol.*, vol. 16, no. 2, pp. 180–186, 2023, doi: 10.34151/jurtek.v16i2.4512.
- [9] K. B. Rohito, K. R. Dantes, and I. N. P. Nugraha, "Rancang Bangun Air Cooler Dengan Menggunakan Modul Termoelektrik Peltier Type Tec-12706," *J. Pendidik. Tek. Mesin Undiksha*, vol. 7, no. 3, pp. 122–128, 2019, doi: 10.23887/jptm.v7i3.26516.
- [10] Z. Fakhri, A. Daelami, Bayudin, and A. Charisma, "Sistem Pengaturan Pendingin Ruangan dengan Menggunakan Thermoelectric dan Blower Motor Direct Current," *J. Tek. Media Pengemb. Ilmu dan Apl. Tek.*, vol. 21, no. 1, pp. 84–94, 2022, doi: 10.55893/jt.vol21no1.430.



Citation of this Article:

Muchammad, Muhammad Tafarel Firjatullah, & Budi Setiyana. (2025). Effectiveness Test of a Cross-Flow Air Cooler Heat Exchanger (Steady State). *International Current Journal of Engineering and Science (ICJES)*, 4(10), 5-10. Article DOI: <https://doi.org/10.47001/ICJES/2025.410002>
