JOURNAL OF PETROLEUM AND GEOTHERMAL TECHNOLOGY
ISSN: 2723-0988, e-ISSN: 2723-1496

Vol. 6 No. 1 2025

Design Analysis of Shell and Tube Type Recuperator in Organic Rankine Cycle Power Plant with Low-Temperature Geothermal Steam Source

Muhammad Rifqi Dwi Septian [1*], Fitri Rusmaladewi [1], Rozi Afdi [1], Friska Hasugian [1], Dwi Miftha Kurnia [1], Stevy Canny Louhenapessy [1], Setiadi Wira Buana [2]

[1] Oil and Gas Engineering, Institut Teknologi Sumatera

[2] Energy System Engineering, Institut Teknologi Sumatera

* corresponding email: muhammad.s@rmg.itera.ac.id muhammadifqids@gmail.com

ABSTRACT

Organic Rankine Cycle (ORC) power generation systems offer an effective means to harness low-grade geothermal heat. A crucial component in improving ORC thermal performance is the recuperator, which recovers residual heat from the turbine outlet to preheat the working fluid. This study focuses on the design and evaluation of a shell and tube recuperator using R-600a as the working fluid, through thermodynamic and heat transfer analyses. Key parameters such as LMTD (32.38 °F), effectiveness (0.434), and heat transfer area (60.35 m²) were calculated. Pressure drops were within acceptable limits (tube side: 4.46 psi; shell side: 0.475 psi), and the dirt factor of 0.0038 indicates good resistance to fouling. The results support the feasibility of implementing the proposed design in small to medium-scale geothermal ORC applications.

Keywords: geothermal; ORC; recuperator; shell and tube; thermal analysis

I. INTRODUCTION

The increasing global demand for electricity has driven the need for energy systems that are both efficient and environmentally friendly. Indonesia possesses vast geothermal potential, much of which is classified as low- to medium-temperature resources (below 180 °C), making them less suitable for conventional power generation technologies. In such contexts, ORC systems are promising alternatives due to their ability to convert low-grade heat into electrical energy using organic working fluids.

In ORC systems, a recuperator serves to improve system efficiency by transferring residual heat from the turbine exhaust to preheat the working fluid before it enters the evaporator. While shell and tube heat exchangers are commonly used in industrial settings, their specific design optimization for low-grade geothermal ORC systems remains underexplored. This study aims to address this gap by presenting a comprehensive thermal and mechanical design analysis of such a recuperator.

II. METHODS

The design methodology combined energy balance, thermodynamic equations, and empirical design standards for shell and tube heat exchangers. The key stages include:

1. Performing energy and mass balance to quantify heat absorbed and released.
2. Calculating the Log Mean Temperature Difference (LMTD), applying a correction factor $F_t = 0.95$
3. Determining recuperator geometry using the effectiveness–NTU method.
4. Estimating pressure losses on both shell and tube sides using the Darcy–Weisbach equation.
5. Evaluating fouling resistance using the dirt factor.

The working fluid selected for this study was R-600a, with an inlet temperature of 38.8 °C and an outlet temperature of 74.5 °C. The hot fluid (turbine exhaust gas) entered the recuperator at 100.7 °C and exited at 42.5 °C. The mass flow rate of the working fluid was 15000 lb/hr, and that of the heating fluid was 17000 lb/hr.

Calculations were performed using established heat transfer correlations and design assumptions drawn from standard references. The total heat transfer (Q) was calculated using the fundamental heat exchanger equation:

$$Q = U \times A \times \Delta Tlm \times F \tag{1}$$

Where:

- Q = total heat transferred (W or Btu/hr)
- U = overall heat transfer coefficient ($W/m^2 \cdot K$)
- A = heat transfer area (m^2)
- ΔTlm = log mean temperature difference (°C or °F)
- F = correction factor (dimensionless)

The effectiveness (ε) was evaluated using the NTU method:

$$\varepsilon = Q / Qmax = Q / [Cmin \times (Th,in - Tc,in)] \tag{2}$$

Where:

- Cmin = minimum heat capacity rate (W/K)
- Th,in and Tc,in = inlet temperatures of hot and cold streams, respectively

Pressure drop (ΔP) on the tube side was estimated using the Darcy–Weisbach equation:

$$\Delta P = f \times (L/D) \times (\rho v^2 / 2) \tag{3}$$

Where:

- f = friction factor
- L = tube length (m)
- D = tube diameter (m)
- ρ = fluid density (kg/m^3)
- v = fluid velocity (m/s)

III. RESULTS AND DISCUSSION

3.1. Heat Load and LMTD

Heat Load and LMTD Based on energy balance calculations, the R-600a working fluid absorbs 771,154 Btu/hr, while the heating fluid releases 798,086.8 Btu/hr, with a deviation of 3.37%—acceptable within a design tolerance of <10%. The corrected LMTD value is 32.38 °F, after applying a correction factor Ft = 0.95.

Table 1. Inlet and Outlet Conditions of Working and Heating Fluids

Fluid Type	Inlet Temperature (°C)	Outlet Temperature (°C)	Mass Flow Rate (lb/hr)
R-600a (Working)	38.8	74.5	15,000
Heating Fluid	100.7	42.5	17,000

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Table 2. Recuperator Design Specifications

Parameter	Value	Unit
Shell Diameter	**24**	**Ft**
Number of Tubes	**160**	
Tube Length	**19.685**	**Ft**
Heat Transfer Area	**60.35**	**m^2**
Tube Outer Diameter	**0.75**	**Inch**
Tube Thickness	**1.25**	**mm**
Baffle Spacing	**0.5**	**Ft**

3.2. Effectiveness and Performance

The recuperator's effectiveness was calculated at **0.434**, exceeding the minimum threshold (0.4), thereby indicating efficient heat recovery under the prescribed flow and thermal conditions.

3.3. Pressure Drop Analysis

The pressure drops were estimated to be **4.46 psi** on the tube side and **0.475 psi** on the shell side. Both values are within acceptable limits for ORC equipment (tube max: 10 psi, shell max: 2 psi). The trend from Figures 1 and 2 shows that increasing the mass flow rate results in increased pressure drops, with a more significant impact on the tube side due to geometry and flow velocity constraints. This is consistent with Darcy–Weisbach principles and the expected behavior of compact heat exchangers.

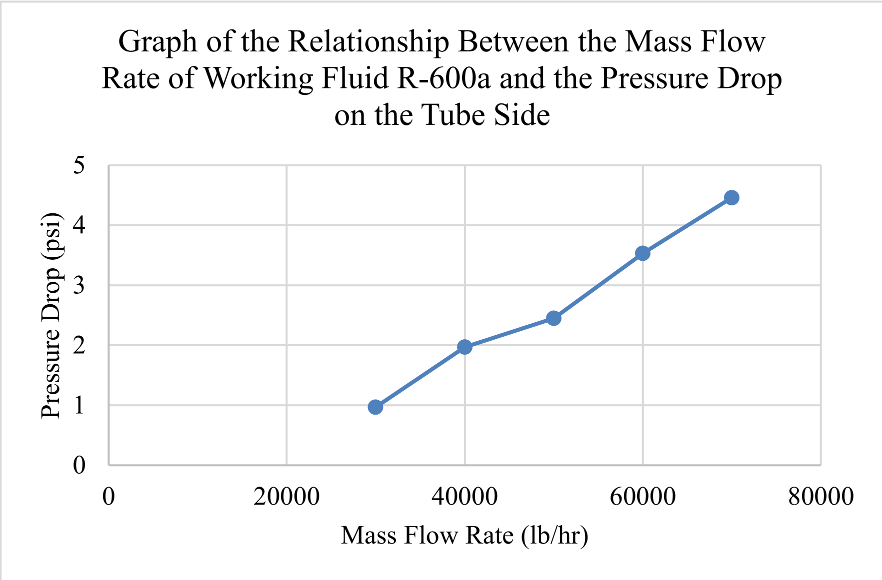

Figure 1. Relationship Between R-600a Working Fluid Flow Rate and Tube-Side Pressure Drop

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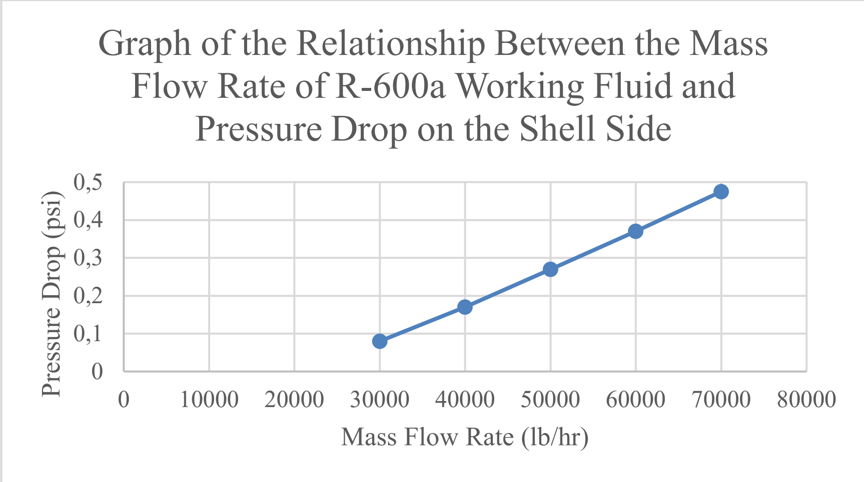

Figure 2 Relationship Between R-600a Working Fluid Mass Flow Rate and Shell-Side Pressure Drop

Based on Figures 1 and 2, the graphs showing the relationship between the mass flow rate of the working fluid (R-600a) and the pressure drop on both the tube and shell sides indicate that an increase in mass flow rate leads to a corresponding increase in pressure drop on both sides. However, the pressure drops increases more significantly on the tube side due to the geometry and flow characteristics. These results are consistent with the head loss theory (Darcy-Weisbach equation) and the principles of shell-and-tube heat exchanger design. Despite the increase in pressure drop with higher flow rates, all values remain within the design tolerance limits (maximum: 10 psi for the tube side and 2 psi for the shell side). Therefore, the design is considered hydraulically efficient and feasible for use in an ORC system utilizing R-600a as the working fluid and low-temperature geothermal heat as the energy source.

3.4. Fouling Resistance

The dirt factor was determined to be **0.0038**, marginally above the baseline of 0.003. This reflects **strong resistance to fouling**, a desirable characteristic for prolonged geothermal operation with minimal maintenance interruption.

IV. CONCLUSION

The design and analysis of a shell and tube type recuperator in an Organic Rankine Cycle (ORC) system utilizing low-temperature geothermal steam and R-600a as the working fluid have demonstrated favorable results. The calculated Log Mean Temperature Difference (LMTD) of 32.38 °F, effectiveness of 0.434, and heat transfer area of 60.35 m² indicate that the recuperator meets the required thermal performance standards for ORC systems.

Hydraulically, the recuperator design proves to be efficient, with pressure drops of 4.46 psi on the tube side and 0.475 psi on the shell side—both well within the acceptable design limits. These outcomes confirm that the exchanger can operate effectively without causing significant head losses. Furthermore, the low dirt factor of 0.0038 implies strong resistance to fouling, suggesting long-term durability and low maintenance requirements.

In summary, the proposed recuperator design is technically feasible for application in small- to medium-scale geothermal power plants. It contributes to improving thermal efficiency in ORC systems operating with low-grade geothermal heat sources.

REFERENCES

Journal:

Buntoro, A., Nurcholis, M., Rahmad, B., & Lukmana, A. H. (2020). Application of Fracture Barrier Analysis in Well Stimulation Planning for Upper Baturaja Limestone Formation Based on Well Log & Drill Cutting Data from OBF-01 and OBF-04 Wells, Offshore Southeast Sumatra. *Journal of Petroleum and Geothermal Technology (JPGT)*, *1*(2), 50–61.

Ammar, Y., Joyce, S., Norman, R., Wang, Y., & Roskilly, A. P. (2012). Low grade thermal energy sources and uses from the process industry in the UK. *Applied Energy*, *89*(1), 3–20. https://doi.org/10.1016/j.apenergy.2011.06.003

Bao, J., & Zhao, L. (2013). A review of working fluid and expander selections for organic Rankine cycle. *Renewable and Sustainable Energy Reviews*, *24*, 325–342. https://doi.org/10.1016/j.rser.2013.03.040

Bojic, I., & Nikolic, D. (2020). Recuperator design for the ORC cycle: Parametric optimization study. *Energy Conversion and Management*, *207*, 112523. https://doi.org/10.1016/j.enconman.2020.112523

Loni, R., Mahmoud, S., Hughes, B. R., & Al-Sulaiman, F. A. (2021). A comprehensive review of organic Rankine cycle system modelling and simulation. *Renewable and Sustainable Energy Reviews*, *135*, 110208. https://doi.org/10.1016/j.rser.2020.110208

Ming, T., Zhang, H., Li, Q., Wang, X., & Liu, Y. (2013). A new design method for the shell-and-tube heat exchanger based on minimum entropy generation. *Applied Thermal Engineering*, *54*, 62–70. https://doi.org/10.1016/j.applthermaleng.2013.01.031

Tchanche, B. F., Lambrinos, G., Frangoudakis, A., & Papadakis, G. (2011). Low-grade heat conversion into power using organic Rankine cycles – A review of various applications. *Renewable and Sustainable Energy Reviews*, *15*(8), 3963–3979. https://doi.org/10.1016/j.rser.2011.07.024

Wang, E. H., Zhang, H. G., Zhao, Y., Fan, B. Y., Wu, Y. T., & Mu, Q. H. (2011). Performance analysis of a novel system combining a dual loop organic Rankine cycle (DORC) with a gasoline engine. *Applied Energy*, *88*(11), 3760–3771. https://doi.org/10.1016/j.apenergy.2011.05.024

Zhang, J., He, Y. L., & Tao, W. Q. (2016). Performance analysis of organic Rankine cycle with low-grade heat sources. *Energy*, *94*, 20–31. https://doi.org/10.1016/j.energy.2015.10.135

Proceedings:

Lukmana, A. H., Putradianto, R. R., Bintarto, B., & Asmorowati, D. (2020, July). Engineering design and cost estimation of geothermal brine utilization for meeting room heating. In *AIP Conference Proceedings* (Vol. 2245, No. 1). AIP Publishing.