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Comparative Study of Single Flash Steam–ORC and Back Pressure Steam–ORC Configurations in Geothermal Power System

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Abstract: To support Indonesia's goal of achieving net-zero emissions by 2060, optimizing the utilization of renewable energy sources is essential. In geothermal systems, brine—commonly considered waste—can be further harnessed to maximize resource efficiency and sustainability. The Organic Rankine Cycle (ORC) presents a promising technology to significantly increase the power output and efficiency of geothermal power plants. This study aims to evaluate the turbine power output of two power generation system configurations integrated with ORC technology, using three different working fluids: Iso-pentane, R-290, and R-1234. The research method involves the development of mathematical and thermodynamic models to simulate and analyze energy conversion processes and calculate turbine power output in each configuration. The results show that the back pressure steam–ORC configuration generates substantially higher total power than the single flash steam–ORC system. Specifically, the back pressure system achieves 33.53 MW with Iso-pentane, 39.3 MW with R-290, and 47.6 MW with R-1234. The performance improvement is most significant when using R-1234, with a 19 MW increase compared to the single flash configuration. Meanwhile, the increase is only 1.46 MW for Iso-pentane and 0.8 MW for R-290. These findings highlight the superior efficiency of the back pressure steam–ORC configuration, particularly when paired with R-1234, as a promising solution for enhancing geothermal energy utilization in Indonesia.

Keywords: Organic Rankine Cycle, Single Flash Steam, Back Pressure, Geothermal Energy

INTRODUCTION

Indonesia, situated along the world's ring of fire, boasts significant geothermal potential. This is evidenced by its 117 active volcanoes scattered across the archipelago. The country's geothermal energy potential is estimated to account for about 40% of the world's total, roughly translating to around 28,617 MW (Nasruddin et al., 2016). Indonesia aims to achieve a 23% renewable energy mix by 2025 and net-zero emissions by 2060, with geothermal energy contributing approximately 5% to the national energy mix and about 40% to the total renewable energy contribution (Pambudi & Ulfa, 2024). However, based on data from Pertamina Geothermal Energi in 2025, the installed capacity of geothermal power plants stands at only 2.8 GW, which is about 9.8% of Indonesia's total geothermal potential. Therefore, it is crucial to maximize the utilization of the existing installed capacity to support further development in this sector.

Organic Rankine Cycle technology holds great potential to substantially enhance geothermal power plants' power output and efficiency while contributing to Indonesia's goals for renewable energy development and environmental sustainability (Prasetyo et al., 2024). The Organic Rankine Cycle (ORC) is particularly well-suited for the low-temperature recovery of waste heat (Chowdhury & Ehsan, 2023). The Sorik Marapi geothermal plant demonstrated that an Organic Rankine Cycle (ORC) system using R245fa as the working fluid and a brine mass flow rate of 13.63 kg/s could generate 328.07 kW of turbine power, achieving an evaporator efficiency of 4.93% (Melysa et al., 2024).

In another study, the GE Clean Cycle unit operating at 125 kW with 150°C brine and a flow rate of 63 kg/s reached a net thermal efficiency of 11.65% (Fahlevi, 2023). These studies highlight that integrating ORC technology significantly enhances the utilization of low-enthalpy brine, which would otherwise go to waste. This improvement boosts thermal efficiency and supports the development of more sustainable geothermal energy (Zinsalo et al., 2022). The objective of this study is to determine the turbine power output from two types of power generation systems integrated with an Organic Rankine Cycle (ORC), using three different working fluids: Iso-pentane, R-290, and R-1234.

RESEARCH METHOD

Initial Data

The first step of this study involves the definitive collection of essential calculation data, specifically focusing on parameters that remain constant throughout the research.

Table 1. Steam and Brine Data

Position	Stage	m (kg/s)	P (bar)	T (^{0}C)	h (kj/kg)	s (kj/kg.K)	Condition
Inlet Evaporator	3	199.386	6.03	160.7	678.61	1.949772	Saturated Liquid
Inlet Turbine	4	52.6222	6.03	160.7	2760.48	6.767012	Superheate d Vapor

These critical parameters include the pressure, temperature, and mass flow rate of both the brine and the steam before entering the turbine. A detailed overview of these parameters is presented in Table 1.

Assumptions

The assumptions used in this study are as follows:

- The process operates under steady-state conditions, and each component in the cycle is analyzed based on a control volume approach.
- All processes involving the working fluid are assumed to be internally reversible.
- Kinetic and potential energy changes are considered negligible.
- The pinch point temperature is assumed to be 70^0C.
- The outlet pressure of the steam turbine is assumed to be 0.6 bar, and the steam temperature entering the evaporator is assumed to be 95^0c

System Description

The **Single Flash Steam** system is one of the most commonly used methods in geothermal power generation, particularly effective for geothermal fluids with medium to high temperatures (180^0C – 250^0C) (DiPippo, 2016). The process begins by extracting geothermal fluid from underground reservoirs through production wells. When the pressure of the fluid is rapidly reduced via an expansion valve, a portion of the liquid water spontaneously vaporizes (flashes) into steam. This steam-liquid mixture is directed into a separator, where the steam is isolated and then routed to a turbine to drive a generator and produce electricity.

After passing through the turbine, the steam is condensed in a condenser, and the resulting liquid is either discharged or reused. The remaining liquid from the separator (brine) is typically reinjected into the reservoir to maintain system balance. The working principle of this system can be seen more clearly in Figure 1 and Figure 2. Due to its relatively simple design and operational efficiency at high-temperature resources, the single flash steam system is a widely adopted choice in geothermal fields around the world, including many in Indonesia (Assad et al., 2021).

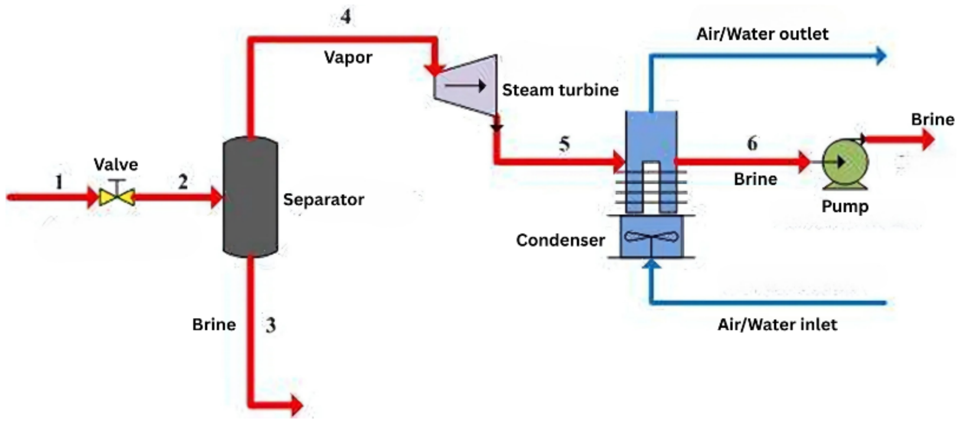

Figure 1. Single Flash Steam System

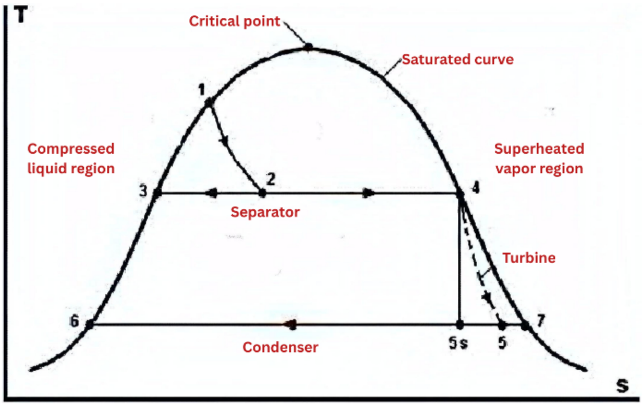

Figure 2. T-S Diagram for Single Flash Steam (DiPippo, 2016)

The **Organic Rankine Cycle (ORC)** is a process that generates electricity from low- to medium-temperature heat sources. It uses organic working fluids with low boiling points, allowing for efficient energy conversion from geothermal brine (Jiménez-García et al., 2023). The cycle comprises four critical processes: pumping, vaporization, expansion, and condensation, all functioning within a closed loop (Sun & Peng, 2025). The process begins with the pressurization of the organic working fluid, which is in liquid form, by a pump. Subsequently, this pressurized liquid is heated in an evaporator utilizing an external heat source, which is brine, until it transforms into high-pressure steam (Wang et al., 2024). The generated vapor then passes through a turbine, where it is expanded to produce mechanical energy, which is subsequently converted into electricity by a generator. To complete the cycle, the vapor is cooled and condensed back into liquid form within a condenser (Wang et al., 2024). A clearer illustration of the ORC system's working principle is provided in Figure 3 and Figure 4.

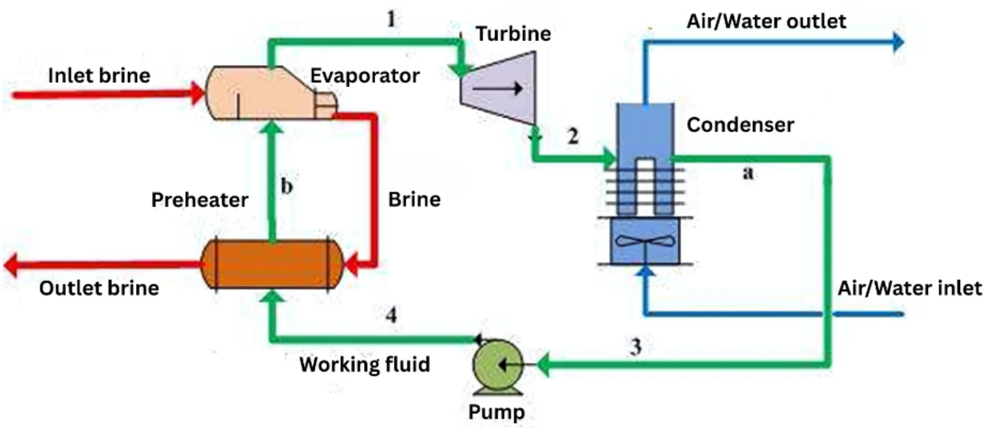

Figure 3. Organic Rankine Cycle System

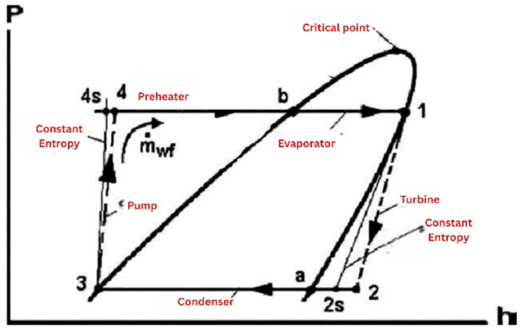

Figure 4. T-S Diagram for Organic Rankine Cycle (DiPippo, 2016)

The **back-pressure turbine system** in geothermal power plants, as shown in Figure 5, operates by utilizing geothermal steam to generate electricity, where the steam exhaust is not condensed but instead discharged at higher pressure for further use (Ahmad et al., 2023).

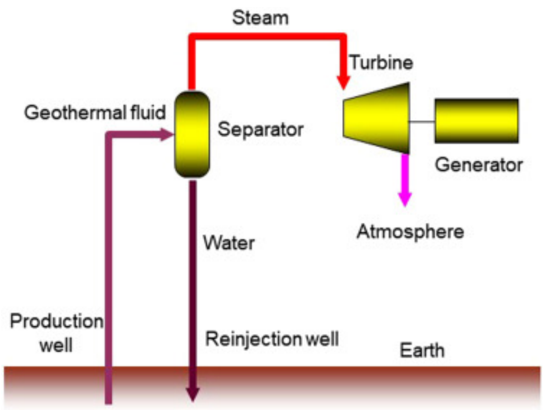

Figure 5. Back Pressure System (Cornell et al., 2022)

Back-pressure turbines, unlike condensing turbines, maintain higher exhaust pressure, making them suitable for combined heat and power applications or for integration with secondary systems such as Organic Rankine Cycles, which focus on maximizing energy extraction by condensing steam to low pressure (Moh Jaelani et al., 2022). This system does not require a condenser and a complex cooling system, so it can reduce construction and maintenance costs compared to a condensing system.

Calculation process

The data processing steps in this study begin by inputting the initial data values, which include fixed parameters such as pressure, temperature, and mass flow rate at various points in the system. These parameters serve as the foundation for further analysis. Next, the thermodynamic properties at each stage of the cycle are calculated using R-290 as the working fluid, including enthalpy, entropy, and phase conditions. After determining these properties, the turbine power output is calculated for both the single flash steam–ORC and the back pressure steam–ORC configurations. The entire calculation process is then repeated for each configuration using two additional working fluids, namely Iso-pentane and R-1234, to compare their performance. Finally, a comparative analysis is conducted based on the thermodynamic properties and the total turbine power generated for each working fluid and configuration.

RESULT AND DISCUSSION

In the Single Flash Steam–ORC system, the brine from the separator outlet, which has a temperature of 160.7°C, is utilized to raise the temperature and change the phase of the working fluid into saturated vapor, enabling the working fluid to drive the turbine. The brine that has been used to increase the energy of the working fluid is then reinjected into the injection well together with the condensed brine from the steam turbine outlet. This system is designed without a gas removal system, which is typically used to reduce the non-condensable gas (NCG) content in geothermal fluids. The schematic of this combined power generation system can be seen in Figure 6.

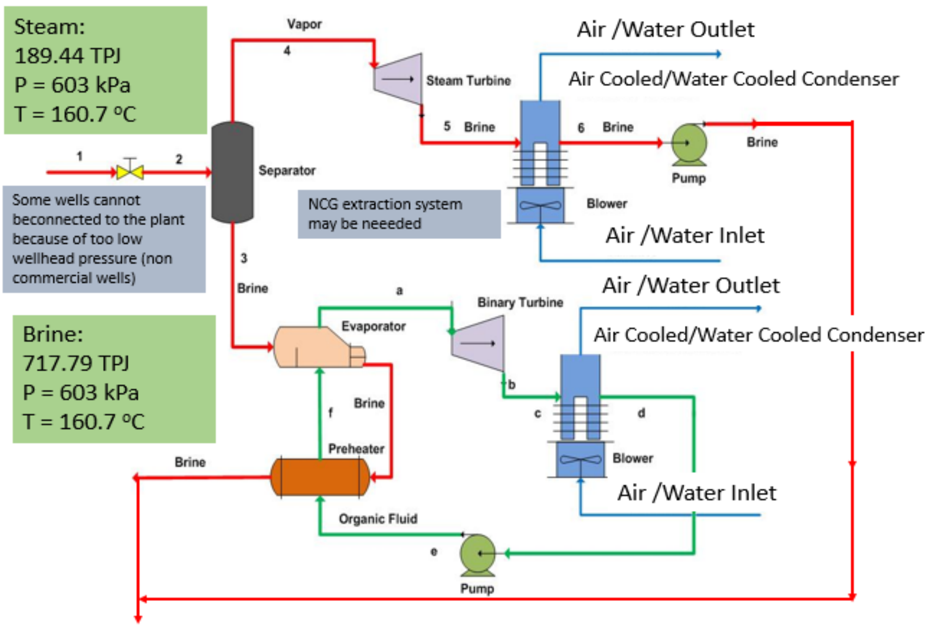

Figure 6. Single Flash Steam–ORC System

There are two types of turbines used in this system: a steam turbine and a binary turbine. The steam turbine operates using high-pressure geothermal steam obtained from the production well after undergoing separation from the brine. This turbine converts the thermal energy of the steam into mechanical energy, which is then used to generate electricity. Meanwhile, the binary turbine is part of the Organic Rankine Cycle (ORC) system, which utilizes the residual heat from the separated brine to vaporize a secondary working fluid with a lower boiling point.

Table 2. Thermodynamic analysis of steam and brine in single flash steam-ORC system

Steam dan Brine							
Position	**Stage**	**m (kg/s)**	**P (bar)**	**T (⁰C)**	**h (kj/kg)**	**s (kj/kg.K)**	**Condition**
Inlet Evaporator	3	199.386	6.03	160.7	678.6184	1.949772	Saturated Liquid
Inlet Steam Turbine	4	52.6222	6.03	160.7	2760.4824	6.767012	Superheated Vapor
Outlet Steam Turbine	5	52.6222	0.6	85.9258	2378.4867	6.767012	(S5=S4)
Inlet Condensor	6	52.6222	0.6	85.9258	359.83652	1.145244	Saturated Liquid
Outlet Evaporator	7	199.386	6.03	95	398.41383	1.249796	Compressed Liquid

Table 3. Thermodynamic analysis of R-290 in single flash steam-ORC system

Working Fluid R-290							
Position	**Stage**	**m (kg/s)**	**P (bar)**	**T (^{0}C)**	**h (kj/kg)**	**s (kj/kg.K)**	**Condition**
Inlet Binary Turbine	a	166,4102	9.52	25	600.84	2.35	Saturated Vapor
Outlet Binary Turbine	b	166,4102	1				Superheated
Inlet Condensor	c	166,4102	1	-42.29	490	2.35	Saturated (Sa=Sc)
Inlet Pump	d	166,4102	1	-42.29	99.5	0.6052	Saturated Liquid
Inlet Preheater	e	166,4102	9.52	0	200	1.2	Compressed Liquid
Inlet Evaporator	f	166,4102	9.52	25	265.11	1.2246	Saturated Liquid

The process that occurs as the fluid passes through the turbine is isentropic, and the values marked in red are assumed values. As seen in Table 2, the enthalpy of the fluid at the steam turbine inlet is higher than at other stages, approximately 2760 kJ/kg. This is because the steam from the separator outlet produces superheated vapor. Meanwhile, the working fluid at the binary turbine inlet has a lower enthalpy, approximately 600 kJ/kg, as shown in Table 3.

Based on the analysis and calculations conducted using thermodynamic analysis, the total power output generated from the Single Flash Steam–ORC system using R-290 as the working fluid is 38.5 MW, of which this total, 21.8 MW is produced by the steam turbine, while 18.4 MW is generated by the binary turbine. It can be observed that the steam turbine generates more power than the ORC system. This is because the energy contained in the brine is not directly used to generate power; instead, it is utilized to increase the energy of the working fluid. As a result, not all of the energy in the brine is used to drive the turbine. The difference in power output is not significantly large when compared to the difference in energy content between the brine and the steam. The brine has an enthalpy of approximately 678 kJ/kg, whereas the steam has an enthalpy of around 2760 kJ/kg.

Figure 7 illustrates the schematic of a back pressure system, in which the brine from the separator outlet is directed to the evaporator in the ORC system to change the phase of the R-290 working fluid into superheated vapor with a high pressure of 9.52 bar, enabling it to drive the binary turbine.

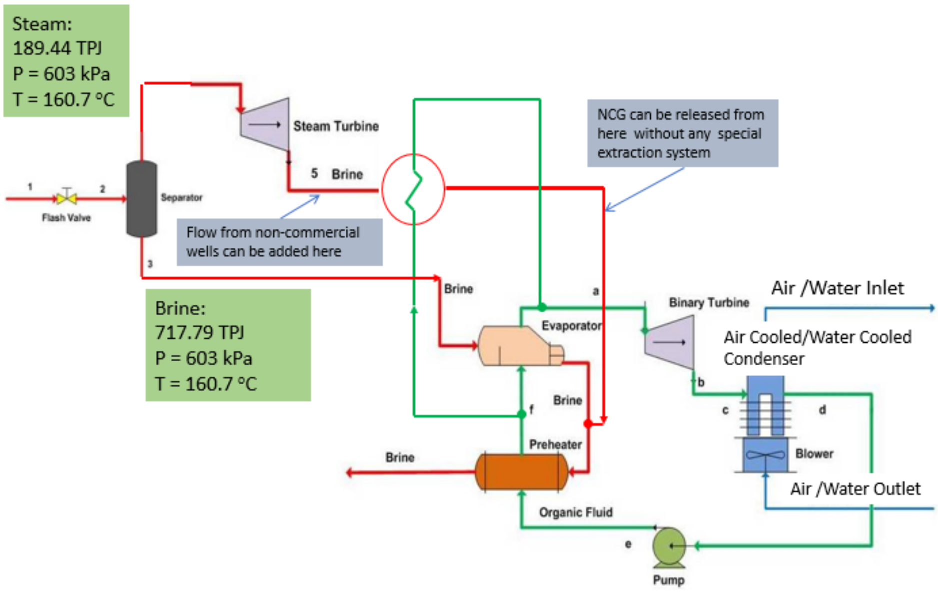

Figure 7. Back Pressure Steam–ORC System

Meanwhile, the brine from the steam turbine outlet is routed to the preheater, where it serves to increase the temperature of the R-290 working fluid before entering the evaporator. This cascading use of heat sources enhances overall cycle efficiency, reduces thermal losses, and represents an effective integration strategy in geothermal binary systems, especially when aiming to utilize low- to medium-enthalpy resources.

Table 4. Thermodynamic analysis of steam and brine in back pressure steam-ORC system

Brine dan Steam							
Position	**Stage**	**m (kg/s)**	**P (bar)**	**T (^{0}C)**	**h (kj/kg)**	**s (kj/kg.K)**	**Condition**
Inlet Evaporator	3	199.386	6.03	160.7	678.6184	1.949772	Saturated Liquid
Inlet Turbine	4	52.6222	6.03	160.7	2760.482	6.767012	Superheated Vapor
Outlet Turbine	5	52.6222	0.6	85.9258	2378.486	6.767012	(S5=S4)
Inlet Preheater	7	252.008	6.03	95	398.4138	1.249796	Saturated Liquid

Brine dan Steam							
Position	**Stage**	**m (kg/s)**	**P (bar)**	**T (^{0}C)**	**h (kj/kg)**	**s (kj/kg.K)**	**Condition**
Outlet Evaporator	7'	199.386	6.03	95	398.4138	1.249796	Saturated Liquid
Outlet Recuperator	7"	52.6222	0.6	95	2671.1244	7.581352	Saturated Liquid

Table 5. Thermodynamic analysis of working fluid R-290 in back pressure steam-ORC system

Working Fluid R-290							
Position	**Stage**	**m (kg/s)**	**P (bar)**	**T (^{0}C)**	**h (kj/kg)**	**s (kj/kg.K)**	**Condition**
Inlet Turbine	a	166,41	9.52	25	605,42	2,35	Superheated Vapor
Outlet Evaporator	a'	83,205	9.52	25	600,84	2,35	Saturated Vapor
Outlet Rcuperator	a"	83,205	9.52	50	610		Saturated Vapor
Outlet Turbine	b	164,170	1				Superheated
Inlet Condensor	c	164,170	1	-42,29	490	2,35	Saturated (Sa=Sc)
Inlet Pump	d	164,170	1	-42,29	99,5	0,6052	Saturated Liquid
Inlet Preheater	e	164,170	9.52	0	200	1,2	Compressed Liquid
Outlet Preheater	f	164,170	9.52	25	265,11	1,2246	Saturated Liquid
inlet evaporator	f'	82,0853	9.52	25	265,11		Saturated Liquid
inlet Rcuperator	f"	82,0853	9.52	25	265,11		Saturated Liquid

Similar to the calculations performed in the previous system, based on thermodynamic analysis as shown in Table 4 and Table 5, the power output in the back pressure steam–ORC system exhibits the same characteristics. The power generated by the steam turbine is greater than the power produced by the ORC system. This observation reinforces the importance of optimizing both stages to achieve maximum overall system efficiency.

In the back pressure steam-ORC system, the total turbine power output is 39.3 MW, which is higher than the output generated by the single flash steam-ORC system. This increased power generation in the back pressure configuration can be attributed to the more efficient use of thermal energy, as it minimizes energy losses typically associated with the condensation process. Furthermore, the continuous utilization of residual heat from both separator brine and steam turbine exhaust within the ORC cycle enhances overall thermal efficiency, resulting in a greater combined power output. Next, a further analysis is carried out to compare the turbine power output using three different types of working fluids. The results of this comparison are shown in Table 6.

Table 6. Total power generated by each configuration using 3 different working fluids

Configuration	Total Power Otuput (MW)		
	Iso-Pentana	R-290	R-1234
Single flash steam-ORC	34.07	38.5	28.6
Back pressure steam-ORC	35.53	39.3	47.6

The results indicate that the back pressure steam–ORC configuration produces more power than the single flash steam–ORC configuration, although the difference is not significant. This outcome is due not only to the inclusion of a preheater, which raises the working fluid temperature to the saturation point, and the evaporator, which transforms the fluid from a saturated liquid to a saturated vapor, but also to the addition of a heat exchanger. This heat exchanger further increases the fluid temperature, converting it into superheated vapor.

In every configuration, the total power generated using R-290 as the working fluid exceeds that produced by Iso-pentane. This is primarily because R-290 evaporates more quickly than Iso-pentane in the evaporator, which accelerates the heat exchange process. Consequently, the energy transfer from the geothermal brine to the working fluid becomes more efficient, resulting in a higher power output.

CONCLUSION

Based on the results of the previous discussion and analysis, it is concluded that:

1. The back pressure steam–ORC configuration demonstrates a significantly higher total power output in comparison to the single flash steam–ORC system. Notably,

when employing three distinct working fluids, the back pressure steam–ORC configuration achieves remarkable power levels: 33.53 MW with iso-pentane, 39.3 MW with R-290, and an impressive 47.6 MW with R-1234. This data underscores the efficiency and effectiveness of the back pressure steam–ORC system, positioning it as a superior option for optimizing energy production.

2. The difference in total power output between the two configurations is most significant when using R-1234 as the working fluid. In the Single Flash Steam–ORC system, the total power generated is 28.6 MW, while in the Back Pressure Steam–ORC system, it reaches 47.6 MW—an increase of 19 MW. In comparison, the increase in total turbine power output using Iso-pentane is only 1.46 MW, and for R-290, the increase is just 0.8 MW. This indicates that R-1234 shows the highest performance improvement when applied in the Back Pressure configuration.

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NOMENCLATURE

m	Mass flow
P	Pressure
T	Temperature
h	Enthalpy
s	Entropy