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Analysis of geothermal power plant process design for Lahendong expansion area

Lahendong bölgesi genişleme alanı için jeotermal enerji santrali süreç tasarımının analizi

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Analysis of Geothermal Power Plant Process Design for Lahendong Expansion Area

Highlights

- *Geothermal process and suitable system conditions at the Lahendong area expansion location*
- *Geothermal process technology of the power generation system between double flash steam or binary cycle*
- *Simulation of double flash steam and binary cycle with regeneration was carried out*
- *The suitability of the process for the expansion of the Lahendong Area Geothermal Power Plant location uses a binary cycle generation system*

Graphical Abstract

Based on the simulation results that have been carried out, the suitability of the process for the expansion of the Lahendong Area Geothermal Power Plant location uses binary cycle technology with a binary cycle generation system.

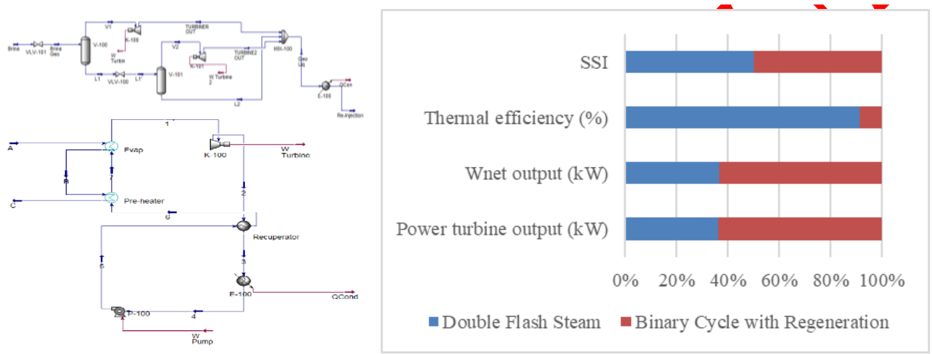

Figure. Comparison of electric power, efficiency, and SSI index on each geothermal power plant technology

Aim

In this research, geothermal process technology and the conditions of the power generation system are compared between double flash steam or binary cycle to determine the technology.

Design & Methodology

A simulation of double flash steam and binary cycle with regeneration at the Lahendong area expansion location was carried out using Aspen Hysys v.11.0.

Originality

This research analyses the suitability of using double flash steam or binary cycle to determine the choice of geothermal generation process technology in expanding the Lahendong Geothermal Plant.

Findings

This work was supported by KEMENDIKBUDRISTEK under the Hibah Penelitian Disertasi Doktor (PDD) number: 112/E5/PG.02.00.PL/2023 and DRPM Institut Teknologi Sepuluh Nopember number: 1910/PKS/ITS/2023.

Conclusion

Based on the results of simulations and calculations that have been conducted, the suitability of the process at the Lahendong Area Geothermal Power Plant expansion site is to use binary cycle technology with a generation system because it produces more power than double-flash steam technology.

Declaration of Ethical Standards

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Analysis of Geothermal Power Plant Process Design for Lahendong Expansion Area

(This study was presented at ECRES 2023 conference.)

Research Article

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ABSTRACT

Indonesia has a geothermal energy resource potential of 40% of the world's potential, and only 8.9% of Indonesia's geothermal potential has just been utilized. The spread of various geothermal locations in Indonesia will affect the characteristics of Geothermal Power Plants with different process types, so analysis is needed to compare geothermal process technology and the conditions of the power generation system between double flash steam or binary cycle to determine the technology. Geothermal process and suitable system conditions at the Lahendong area expansion location. In this research, a simulation of double flash steam and binary cycle with regeneration was carried out. The results were then analyzed based on the highest power output and efficiency. It was found that the double flash steam system produces a power of 3125 kW with a thermal efficiency of 89.8%. Meanwhile, the binary cycle system with regeneration produces a power of 5433.25 kW with a thermal efficiency of 8.68%. Based on the simulation results that have been carried out, the suitability of the process for the expansion of the Lahendong Area Geothermal Power Plant location uses binary cycle technology with a binary cycle generation system.

Keywords: Binary Cycle, Power, Efficiency, Flash Steam, Geothermal Power Plant

Lahendong Bölgesi Genişleme Alani Için Jeotermal Enerji Santrali Süreç Tasariminin Analizi

ÖZ

Endonezya, dünya potansiyelinin %40'ına sahip bir jeotermal enerji kaynağı potansiyeline sahiptir ve sadece Endonezya'nın jeotermal potansiyelinin %8.9'u kullanılmıştır. Endonezya'daki çeşitli jeotermal konumların yayılması, farklı işlem tiplerine sahip Jeotermal Elektrik Santrallerinin özelliklerini etkileyecektir, bu nedenle flaş buhar ve ikili çevrim arasındaki jeotermal işlem teknolojilerini ve enerji üretim sistemi koşullarını karşılaştırmak için bir analiz yapmak gerekmektedir. Lahendong bölgesindeki genişleme konumunda uygun jeotermal işlem ve sistem koşullarını bulmak amacıyla. Bu araştırmada, çift flaş buhar ve rejenerasyonlu ikili çevrimin simülasyonları gerçekleştirildi ve sonuçlar daha sonra en yüksek güç çıkışı ve verimliliğe göre analiz edildi. Çift flaş buhar sisteminin 3125 kW güç ürettiği ve termal verimliliğinin %89.8 olduğu bulundu. Öte yandan, rejenerasyonlu ikili çevrim sistemi, 5433.25 kW güç üretirken, termal verimliliği %8.68'dir. Gerçekleştirilen simülasyon sonuçlarına dayanarak, Lahendong Bölgesi Jeotermal Elektrik Santrali konumunun genişlemesi için en uygun işlemin, ikili çevrim teknolojisi ve rejenerasyonlu ikili çevrim sistemi olduğu sonucuna varıldı.

Anahtar Kelimeler: İkili Çevrim, Güç, Verimlilik, Flaş Buhar, Jeotermal Enerji Santrali.

1. INTRODUCTION

The need for energy use in Indonesia continues to increase with the industrial and population growth pace. Under these conditions, relying solely on fossil fuels whose reserves are depleting will not be able to meet national energy needs. Therefore, Indonesia must develop alternative energy from renewable and sustainable materials to overcome its dependence on fossil-based fuels. One of the renewable energy sources available is stored on the earth worldwide, namely geothermal energy. This available renewable energy source is very safe for the environment because it contributes less CO_2 gas emissions compared to traditional energy sources that rely on fossil-based fuels that can provide a greenhouse effect that can cause global warming [1]. According to Figure 1. As the main player in Indonesia's energy supply strategy, PT. PLN (Pembangkit Listrik Nasional/ Indonesia National Electricity Company) announced a plan to electrify various parts of the country. Renewable energy sources like sun, wind, water, biomass, and geothermal will be combined with non-renewable energy sources like coal, oil, and natural gas [2].

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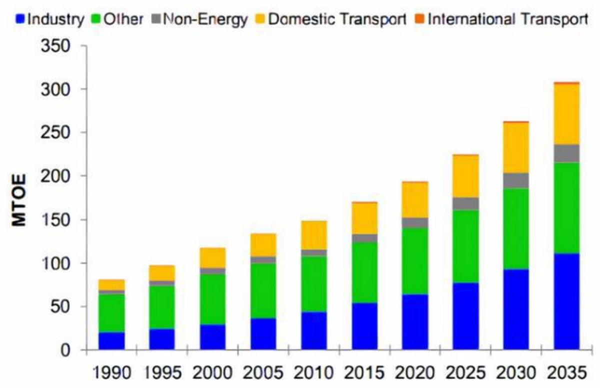

Figure 1. Indonesia's energy sector needs [2] (Figure is in color in the online version of the paper).

Geothermal energy is energy contained as heat in the interior of the earth. The origin of this heat is related to the internal structure of the earth and the physical processes occurring there [3]. Most areas of geothermal activity are given several geographical names for example, the country of Indonesia, which has a lot of geothermal activity, is given a geographical name as the Ring of Fire area. They are referred to as geothermal fields if they are different from and separate from nearby active zones. The phrase is meant to serve as a simple geographical designation without making any generalizations about the more extensive geothermal systems that have generated and sustained field activity. The majority of geothermal locations have several geographical names. For instance, Indonesia, a country with significant geothermal activity, has the geographical term Ring of Fire area.

They are referred to as geothermal fields if they are different from and separate from nearby active zones. The phrase is meant to serve as a simple geographical designation without making any generalizations about the more extensive geothermal systems that have generated and sustained field activity. A geothermal reservoir is a region of the earth's heat field that is so hot and permeable that it can be productively used to generate heat or liquid. The section is only a part of the field and a portion of the underground hot and liquid rocks. Hot but waterproof rocks are not part of the reservoir. It depends on whether current technology can take advantage of the reservoir and the energy price. Drilling deeper into existing fields is a fairly common experience to prove the additional reservoir volume in greater depth [4].

Geothermal technology has been around for a while and is one of the most dependable forms of sustainable energy [5]. Geothermal energy resources in Indonesia have a considerable potential of about 40% worldwide, with an estimated reach of 28.5 Gigawatt electrical (GWe). However, until 2019, based on data from the Directorate of Geothermal, only 8.9% of Indonesia's geothermal potential has been utilized, or around 1130.6 MW. As one of the most potential renewable energy sources, the government continues to encourage the increase in the use of geothermal in Indonesia. The government targets an increase in geothermal utilization to 7241.5 MW or 16.8% in 2025. Efforts to increase the utilization of potential geothermal energy sources by the Government of Indonesia are carried out by establishing Geothermal Power Plants through state-owned companies or granting Geothermal Working Area (WKP) management permits to Independent Power Producers (IPPs).

One of the companies that received direction from the Indonesian government to run a geothermal processing and project business is located in the eastern part of Indonesia, Tomohon City, North Sulawesi Province, since 2001. It has a total capacity of Geothermal Power Plants currently operated 120 MW consisting of a total of six units with a capacity of 20 MW each unit and currently plans to expand the Geothermal Power Plants unit seven, located in Lahendong, and unit eight, located in Tompaso to maintain the availability of energy supplies as well as renewable energy. The characteristics of the steam produced from the well consist of 70% water and 30% steam, which has been directly injecting hot water from the cooling pool into the earth. The scheme of Lahendong Geothermal Plant Unit 3 is given in Figure 3.

The Organic Rankine Cycle (ORC) is a modified cycle from a regular Rankine Cycle whose work fluid is water under pressure and high temperature. The Organic Rankine Cycle (ORC) itself uses a low boiling point. The fluids used are usually silicone oil, hydrocarbon, and fluorocarbon. These fluids have a low boiling point that can replace water as a working fluid on the Organic Rankine Cycle (ORC) [6]. Unlike a regular Rankine Cycle that uses boiling water, the Organic Rankine Cycle (ORC) uses refrigerants that are remembered by low temperatures. Rankine Cycles typically use boilers as heat generators, unlike Organic Rankine Cycle (ORC) cycles that use evaporators or evaporate refrigerant working fluids. The Organic Rankine Cycle does not require combustion because in the evaporator, there is a heat transfer from the wastewater result commonly referred to as evaporation and is called brine [7]. This process does not require a burner such as a boiler, as no combustion process will form no exhaust gas emissions that cause air pollution as a result of the burning process.

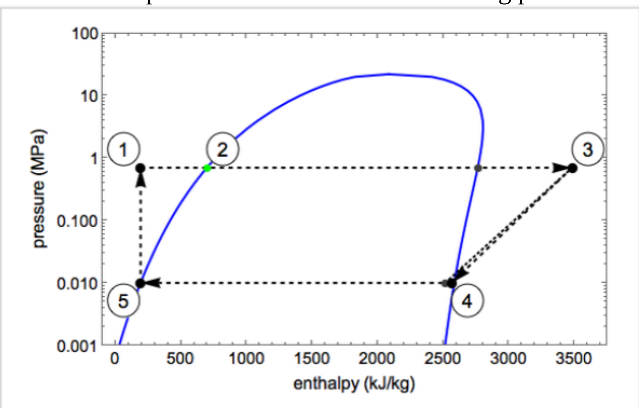

Figure 2. Pressure-enthalpy diagram

Generally speaking, an organic Rankine cycle is the same as a regular Rankine Cycle, i.e., it has four processes, as seen in Figure 2. Diagram P-H (Pressure - enthalpy) in Figure 2 shows that process 1-2 is the expansion process that occurs in the turbine, process 2-3 is the condensation process that happens in the condenser, process 3-4 is the compression process which appears on the pump, and process 4-1 is the evaporation process occurring in the evaporators [8].

Due to their environmental friendliness, low-temperature energy methods, such as solar thermal, geothermal, and low-grade waste heat, are becoming increasingly popular for power generation. These low-temperature energy sources are typically between 80 °C and 150 °C. The most promising heat engines for converting these low-temperature heat sources into electricity are Organic Rankine Cycles (ORCs) [9].

The history of ORCs dates back to the 19th century, and the power sector of the 21st century has given it great attention [10]. In 1904, according to the literature, Willsie created two solar ORC engines with capacities of 4.5 kW and 11 kW, utilizing sulfur dioxide as the working fluid. In 1940, D'Amelio started a geothermal plant with ethylene as its working fluid. It ran until 1950 before being dismantled. When looking at commercial ORC plants, Ormat and Turboden are at the top of the ORC industries. More than 3000 units up to 4 kW and more than 500 units ranging from 1 to 25 MW have been built by Ormat company [11].

The ORCs use organic fluids instead of the generally used Rankine Cycles, which use water as the working fluid (also known as the steam power cycles). Working fluids for ORCs can be categorized into three broad groups based on their behaviour during adiabatic expansion: dry, moist, and isentropic [12]. While large molecule structures exhibit dry behaviour, simple molecular structures behave wetly. Intermediate fluids are isentropic fluids [13]. When selecting a working fluid for a specific ORC application, several working fluid characteristics should be considered, including thermo-physical properties (such as pressure, temperature, specific volume, latent heat, flash point, and specific heat), safety, cost, availability, toxicity, chemical stability at high temperatures, and environmental factors. When compared to the temperatures of the heat source, the fluid's critical temperature and pressure should be acceptable. The cycle's maximum pressure and temperature must be at least 10 °C below the critical limits [6].

This research analyzes the suitability of double flash steam or binary cycle to determine the choice of geothermal generation process technology in expanding the Lahendong Geothermal Plant. The existing Geothermal Power Plants in the Lahendong area use single-flash steam types, as shown in Figure 3. The reason is that the Indonesian government is running a geothermal project in Lahendong to maintain the availability of energy and renewable energy. Apart from that, as one of the most potential renewable energy sources, the Government continues to encourage using geothermal energy in Indonesia utilizing double flash steam and binary cycles. This process does not require a combustion device, such as a boiler, because the absence of a combustion process will not produce exhaust gas emissions, which cause air pollution.

2. STUDY OVERVIEW

In this study, the data on the operating conditions of brine in Table 1 came from brine wellhead cluster 5, which is in Unit-3 Lahendong.

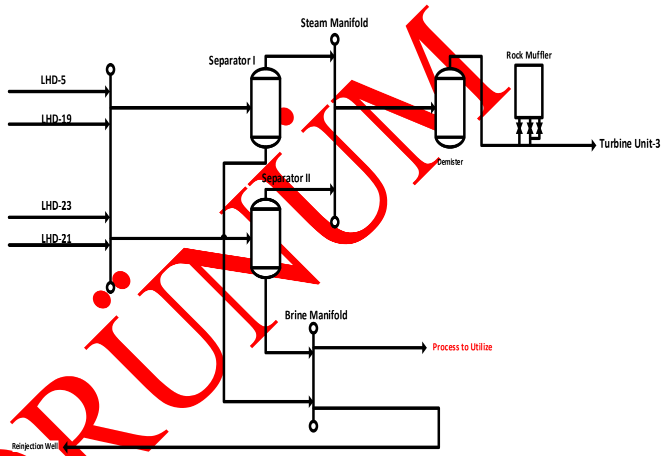

Figure 3. Lahendong Geothermal Plant Unit 3 scheme

Table 1. Operating conditions on a cluster 5 reservoir [14]

Parameters	Value
Brine Temperature	180.8 °C
Brine Pressure	10.23 bar
Mass Flow Rate	624.82 tons/hour

Through this expansion plan, the residual heat in the brine can be utilized to generate electricity before being injected into the injection well. In unit 3, non-condensable gases on the brine will be removed using a scrubber before entering the turbine and The composition on the brine of the well cluster 5 contains non-condensable gases such as CO_2, H_2S, NH_3, Ar, N_2, CH4, H2 and air. As well as for liquid content, there are Na, K, Ca, Mg, NH4, Li, Fe, Al, F, HCO^{3}-, Cl-, SO^{4}-, B, SiO_2, and As [15]. Thus, the brine used in the expansion unit only contains chemicals dissolved in liquid waste brine.

This research analyses the use of Geothermal Power Plants, double flash steam, and binary cycle types to determine the choice of geothermal generation process technology in expanding the Lahendong area. This way, we can obtain the result of double flash steam or binary cycle types.

3. METHODOLOGY

This research method was carried out by collecting data from geothermal power plants in the Lahendong unit and journal references, given in Table 1. This data was used as feed in the Lahendong expansion area.

In simulating geothermal power plant models, double flash steam, and binary cycle with generation technology, Aspen Hysys v.11 software was used. The results were then used to calculate each technology's thermal efficiency and power. The selection of a thermodynamic model to be carried out in this study is influenced by chemical systems and operating conditions such as temperature and pressure, especially for liquid-gas phase changes.

According to [16], for air separation and gas processing and also using organic working fluids, it is recommended to use Peng-Robinson or Soave-Redlich-Kwong thermodynamic models. Based on the selection of these suggestions, this study uses the Peng-Robinson thermodynamic model. The advantage of the Peng-Robinson thermodynamic model lies in the parameters expressed in critical properties for pressure and temperature [16]. The parameters in this study are the default from Aspen Hysys, as shown in Table 2.

Table 2. Parameter of the component from Aspen Hysys

Component	NBP (°C)	Pc (bar)	Tc (°C)	Vc (m^3/ kgmole)
H_2O	100	221	374.15	0.057
n-C_5	36.06	33.75	196.45	0.311

In addition to calculating the thermal efficiency and power output produced in each simulated geothermal plant model. The thermal efficiency using the equation below;

$$\eta_{cc} = 1 - \frac{W_{net}}{Qin} \times 100\% \quad (1)$$

$$W_{net} = Q_{in\ pump+turbin} - Q_{out\ pump+turbin} \quad (2)$$

$$\eta_{cc} = 1 - \frac{Q_{out\ pump+turbin}}{Q_{in\ pump+turbin}} \times 100\% \quad (3)$$

Silica scaling was also considered as one of the criteria in designing geothermal plants since silica (SiO_2) is one of the causes of scaling in geothermal plants [17]. The essential parameters influencing the scaling in geothermal fluids are pH, temperature and pressure. A high pH increases the concentration of carbonate ions, which causes the scaling, while the dissolution of silicates has another trend with changing pH [18]. Two relevant forms are used to analyze the potential for silica formation: quartz and amorphous silica. The concentration of silica in the geofluid produced from the reservoir can be correlated with the geofluid temperature using quartz solubility as a temperature function so that the calculation of quartz concentration using Quartz concentration (Qc) based on reservoir temperature with the following equation:

$$Q_c = 41.598 + (0.23932)t_{brine} - (0.011172)t_{brine}^2 + (1.1713)10^{-4}t_{brine}^3 - (1.9708)10^{-7}t_{brine}^4 \quad (4)$$

At lower temperatures encountered in waste brine after use in power generation (180 °C), the solubility is controlled by an amorphous form of silica. With the equations of Fournier and Marshall, the solubility of amorphous silica [14]:

$$log_{10}s = -6.116 + 0.01625T - 1.758 \times 10^{-5}T^2 + 5.257 \times 10^{-9}T^3 \quad (5)$$

Saturated silica concentrations can be analyzed using the Silica Saturation Index (SSI) as an empirical approach. SSI index is the ratio of silica concentration on brine and amorphous silica solubility [14]. The equation of SSI, namely:

Flash system:

$$SSI = \frac{S_{ii}}{s} \quad (6)$$

Binary system:

$$SSI = \frac{S_i}{s} \quad (7)$$

For the calculation of S_i and S_{ii} are as follows:

$$S_i = \frac{Q_c(t)}{1 - x} \quad (8)$$

$$S_{ii} = \frac{S_i}{1 - x_1} \quad (9)$$

4. RESULT and DISCUSSION

The liquid separated from the Geothermal Power Plant, unit-3 of the Lahendong area, still has a high temperature to be reused. Data were obtained that the temperature of waste brine was 180.8 °C, with a pressure of 10.23 bar and a mass flow rate of 624.82 tons/hour. Several types of geothermal plant process systems can be used in waste brine, including double flash steam and binary cycle with regeneration, shown in Figure 4 and Figure 5. Therefore, geothermal plant modelling was simulated using these two technologies to compare the corresponding geothermal plant technology in the Lahendong area geothermal plant expansion.

Double Flash Steam

In Figure 4, the brine enters the Flash separator (V-100), separating gas and liquid. The gas flow will be expanded using a turbine (K-100), while the liquid flow (L1) will be separated again using a flash separator (V-101). The gas flow from the second flash separator will be mixed (MIX-100) and cooled (E-100) to be injected into the well.

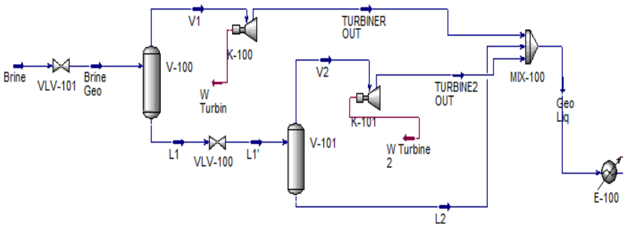

Figure 4. Geothermal plant scheme with double flash steam technology on Aspen Hysys

Based on the simulation, data from Table 3 is obtained with the variable operating pressure of the flash separator that gives the optimal pressure to produce greater power.

Table 3. Operating conditions geothermal plant double flash steam technology with Aspen Hysys with the first $P_{flashing}$ of 6 bars and the second $P_{flashing}$ of 2 bars

Flowsheet	P(bar)	T (ºC)	Mass Rate (Tons/hour)
Brine	10.23	180.8	624.8
Brine Geo	6	158.9	624.8
V1	6	158.9	30.46
L1	6	158.9	594.3
L1'	2	120.2	594.3
Turbine Out	1	99.59	30.46
V2	2	120.2	46.94
L2	2	120.2	547.4
Turbine2 Out	1	99.59	46.94

In Table 3, turbine power 1 (High-Pressure turbine) is 1963 kW, and turbine power 2 (Low-Pressure Turbine) is 1162 kW, so the total power produced is 3125 kW. Therefore, double flash steam technology obtained a thermal efficiency of 89.96%. As for the Carnot cycle, the double flash steam system's efficiency is 21.06%.

Binary Cycle with Regeneration

Figure 5 shows a simulation in Aspen Hysys using a binary cycle with generation technology using n-pentane as the working fluid. The mass of the n-pentane in this cycle is 600 tons/hour (166.67 kg/s).

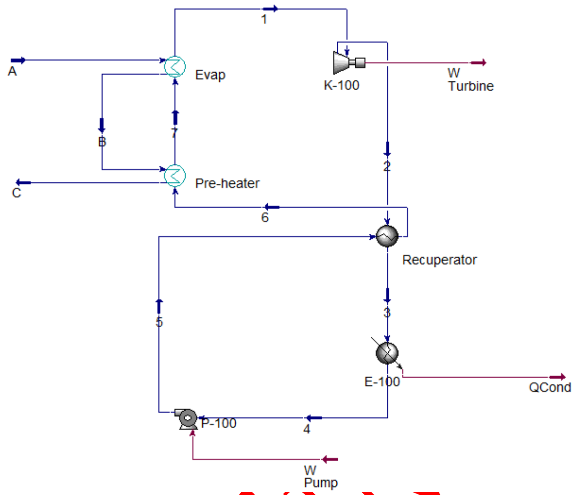

Figure 5. Geothermal plant scheme with binary cycle with regeneration technology on Aspen Hysys

In Figure 5, the brine (A) enters the evaporator (Evap) and contacts with the working fluid (stream 7). Brine from evaporator (B) is used to preheat the working fluid. The working fluid (stream 6) enters the preheater process to change the condition of the working fluid near subcool temperature and change to vapour phase by entering the evaporator. The vapour of the working fluid (stream 1) expands the pressure (K-100) and then enters the recuperator to reuse the rest of the heat of the working fluid. Based on the simulation for the Geothermal Plant scheme with binary cycle with regeneration technology, the result is shown in Table 4.

Table 4. Simulation results of geothermal plant binary cycle with regeneration technology on Aspen Hysys

Stream	P(bar)	T (ºC)	Mass Rate (Tons/hour)
Brine (A)	10.23	180.8	624.8
Brine (B)	10.23	180.8	624.8
Brine (C)	10.23	85.2	624.8
Working fluid (1)	4	90	600
Working fluid (2)	1	64.89	600
Working fluid (3)	1	64.89	600
Working fluid (4)	1	36.1	600
Working fluid (5)	4	36.25	600
Working fluid (6)	4	36.29	600
Working fluid (7)	4	90	600

In Table 4, the turbine power is obtained to produce 5526 kW, while the pump requires 92.75 kW. Therefore, this binary cycle with generation technology produces 5433.25 kW of clean electrical power with a Carnot cycle efficiency in the binary cycle with the generation system of 21.06% and its thermal cycle efficiency of 8.7%. The result follows the literature showing that thermal efficiency in binary cycles is 8-12% [19].

Based on Table 5, the comparison of electrical power, efficiency, and SSI index in double flash steam and binary cycle with regeneration technologies by modelling and simulating using Aspen Hysys v.11.

Table 5. Comparison of electric power, efficiency, and SSI index on each geothermal power plant technology

Process System	Power output (kW)		Thermal efficiency (%)	SSI
	$P_{turbine}$	W_{net}		
Double Flash Steam	3125	3125	89.96	1.265
Binary Cycle with Regeneration	5526	5433.25	8.68	1.260

The largest electrical power is obtained in the binary cycle with regeneration technology. The Binary Cycle is intended for brine heat sources with low and medium temperatures of < 200 ºC. The binary cycle uses a working fluid with a lower boiling point and a higher vapour pressure than water [6] for its thermal cycle efficiency of 8.7%. The result follows the literature showing that thermal efficiency in binary cycles is 8-12% [19].

In addition, saturated silica needs to be analyzed using the Silica Saturation Index (SSI) as an empirical approach, considering that the brine used in geothermal power plants contains silica (SiO2), which can cause scaling. Based on Table 5, it was found that the SSI values in the double flash system and binary system were 1.265 and 1.260, respectively. The design of process conditions in the simulation of geothermal power plant research on binary cycle with generation technology and double flash steam technology can still be operated without scaling from silica since, from the experience of some developments in Geothermal Power plants, it is possible to operate with SSI values greater than one where in double flash systems ≤ 1.30 and binary systems SSI ≤ 2.0 [20].

In selecting a technological system for expanding the Lahendong area, several aspects can be reviewed, such as the required expansion area, focusing on the aspect of utilizing heat to produce greater power, so it would be recommended to use a binary cycle with regeneration, which produces greater power than double flash steam. Apart from that, if the required expansion area focuses on the output temperature, it would be advisable to use double flash steam, which has a higher output temperature than a binary cycle with regeneration. However, both systems have an insufficient output temperature to allow the temperature to be used for re-injection into the well because if it is less than the permitted temperature, it will cause precipitation.

5. CONCLUSION

Based on simulation data that has been obtained using Aspen Hysys V.11 software, the calculation results were obtained that in the double flash steam system using different variables of first flashing pressure and second flashing, it was found that in producing the greatest power in the conditions of the first flashing pressure and the second flashing successively by 6 bar and 2 bar by producing power of 3125 kW and thermal efficiency of 89.96% and SSI value of 1.265. Meanwhile, in the binary cycle with a generation system using variable temperatures on the evaporator, a power of 5433.25 kW was obtained with a thermal efficiency of 8.68% and an SSI value of 1.260. Based on the results of simulations and calculations that have been conducted, the suitability of the process at the Lahendong Area Geothermal Power Plant expansion site is to use binary cycle technology with a generation system because it produces more power than double-flash steam technology.

NOMENCLATURE

h_i	Enthalpy	kJ/kg
$\dot{m}$	Mass Flow	tones/h
P	Pressure	bar
Pc	Critical Pressure	bar
T	Temperature	ºC
Tc	Critical Temperature	ºC
Vc	Critical Volume	m^3/kgmole
T_L	Low Temperature	ºC
T_H	High Temperature	ºC
$\dot{W}$	Work	kW
$Q_{in/out}$	Heat duty in or out	kW
w_t	Turbine Work	kW
η_{cc}	Thermal Efficiency	%
S	Silica Solubility	
S_i	Silica Brine Concentration in the Main Separator	
S_{ii}	Silica Brine Concentration in Flash Vessel	

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Alhafiz Taufiqul HAKIM: Performed the experiments, analysed and wrote the manuscript of the results.

Aisyah Putri Prameswari JASMINE: Performed the experiments and analysed the results.

JUWARI: Supervised in this research.

RENANTO: Supervised in this research and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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