

Utilization of waste heat from separation process of Ulubelu's geothermal power plant by implementing an Absorption Refrigeration System (ARS) to improve plant performance

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Abstract. Utilization of geothermal energy for water-dominated reservoir usually involves a separation process that turns geothermal fluid mixtures into pure steam and brine water. This process also occurred on Ulubelu's geothermal power plant (GPP). As waste energy from the power generation process, the remaining heat energy in brine water is still high enough to run an absorption refrigeration system (ARS). This study proposed an integrated power generation and absorption system that operate side by side for a further cooling process. ARS will be employed to produce a lower temperature of cooling water from the GPP's cooling tower and then pass it to GPP's condenser. The lower temperature of cooling water will affect steam condensation process and the vacuum pressure of condenser, moreover, increase power production and exergy efficiency of Ulubelu's GPP. The improvement of exergy efficiency & production capacity will be observed along with the rise of the investment cost as form as the annual cost of the ARS. A Multi-objective optimization using genetic algorithm will be conducted to minimize exergy efficiency and the annual cost of ARS. The optimization will be conducted using MATLAB along with EES for work fluid properties database. The temperature of generator, absorber, condenser, and evaporator of ARS are used as decision variables. Finally, the effect of integrated system and optimum value for each decision variables are presented in this study.

1. Introduction

Increased demand for energy, decline of energy resources and environmental impact due to energy utilization have resulted to calls for a sustainable approach to development and management of energy resources [1]. Ulubelu is one of several water dominated reservoir in Indonesia [2]. The Ulubelu's geothermal fluid mixtures exploited from the ground need to be separated to extract steam from the liquid.

The extracted steam is then used to drive the turbine which coupled to a generator to produce electricity. The liquid separated from steam called brine water is considered a waste and in most cases is injected back to the ground. However, the waste liquid or brine water possesses a considerable amount of exergy, which can be utilized for other thermal applications such as absorption for cooling purposes. It is therefore clear that exergy efficiency of the geothermal power plant is lowered due to irreversibility during energy conversion process within the subsystems and exergy quality is lost.

In order to improve conversion efficiency of a geothermal power plant, cooling is essential for it increases the heat rejection, raises power output and increases heat to power conversion ratio [3]. Tesha [3] & Nyambane [4] conducted a simulation for integrating single effect absorption



refrigeration system to produce a lower temperature of cooling water used in condenser to enhance the capacity for power generation. The single effect absorption has relatively low COP, therefore, multi effect absorption system with high temperature heat resource have now developed [5] but the research about combining multi effect absorption in geothermal power plant never conducted before.

Arora, et. al [6], Azhar, et. al [7], Ghani, et. al [8] performed energy and exergy of single effect and double effect absorption LiBr-Water system to maximize the COP and exergetic efficiency. Misra, et. al [9] conducted thermo economic optimization for double effect absorption to minimize overall product cost. Shirazi, et. al [10] performed multi-objective optimization of solar powered absorption chiller to find its optimum parameter for energy and economic objective function. But, the multi objective optimization for both objective function never conducted on integrated GPP and absorption refrigeration system. It is important to analyze economic component as the high efficiency of power plant need more cost and it worse for geothermal business. The power plant and absorption refrigeration system needs operational condition with high efficiency and low cost.

This study aims to utilize the heat contained in brine water that leaves from separator by implementing an absorption refrigeration system to improve Ulubelu GPP's performance. ARS will be employed to produce a lower temperature of cooling water from the GPP's cooling tower and then pass it to GPP's condenser. The lower temperature of cooling water will affect steam condensation process and the vacuum pressure of condenser, moreover, increase power production and exergy efficiency of Ulubelu's GPP. To be precise, the objectives are : to optimize the combination of absorption refrigeration cycle and power plant with genetic algorithm optimization from exergy destruction and cost as objectives function with six parameters chosen as decision variables.

2. Description system

The GPP & Absorption refrigeration system in this study consist of several components, there are: separator, turbine, generator, condenser, cooling tower and absorption refrigeration. In this refrigeration system, the components are absorber, high desorber (D2), low desorber (D1), condenser, evaporator and solution heat exchanger (SHX 1 & SHX 2). The schematic diagram is shown in figure 1.

At point 1 in figure 1 the solution rich in refrigerant and a pump forces the liquid through solution heat exchanger 1 and 2 to high desorber (D2). The process increases the temperature in the each SHX. The added thermal energy from brine water of separation process boils the refrigerant from the solution and separates the refrigerant and water. It results in refrigerant vapor (17) flows to condenser, where heat is rejected as the refrigerant condenses in condenser 1. The heat of condensation is utilized by low desorber to separate refrigerant vapor from the weak solution from D1. Secondary vapour is produced on D2 outlet, which the refrigerant vapour together flows to condenser 1. The total amount of liquid refrigerant leaving condenser 1 is sum of refrigerant vapour leaving D1 and D2. The condensed liquid then flows through expansion valve to the evaporator thus lowering its pressure. This change in pressure allows the evaporator temperature to be low enough for refrigerant to absorb heat from the water being cooled (27). the refrigerant evaporates and passes to the absorber where it gets absorbed by strong solution coming from D1 through heat exchanger SHX1. This process produced weak solution in the absorber and then it is pumped to the high desorber and the cycles completes [11].

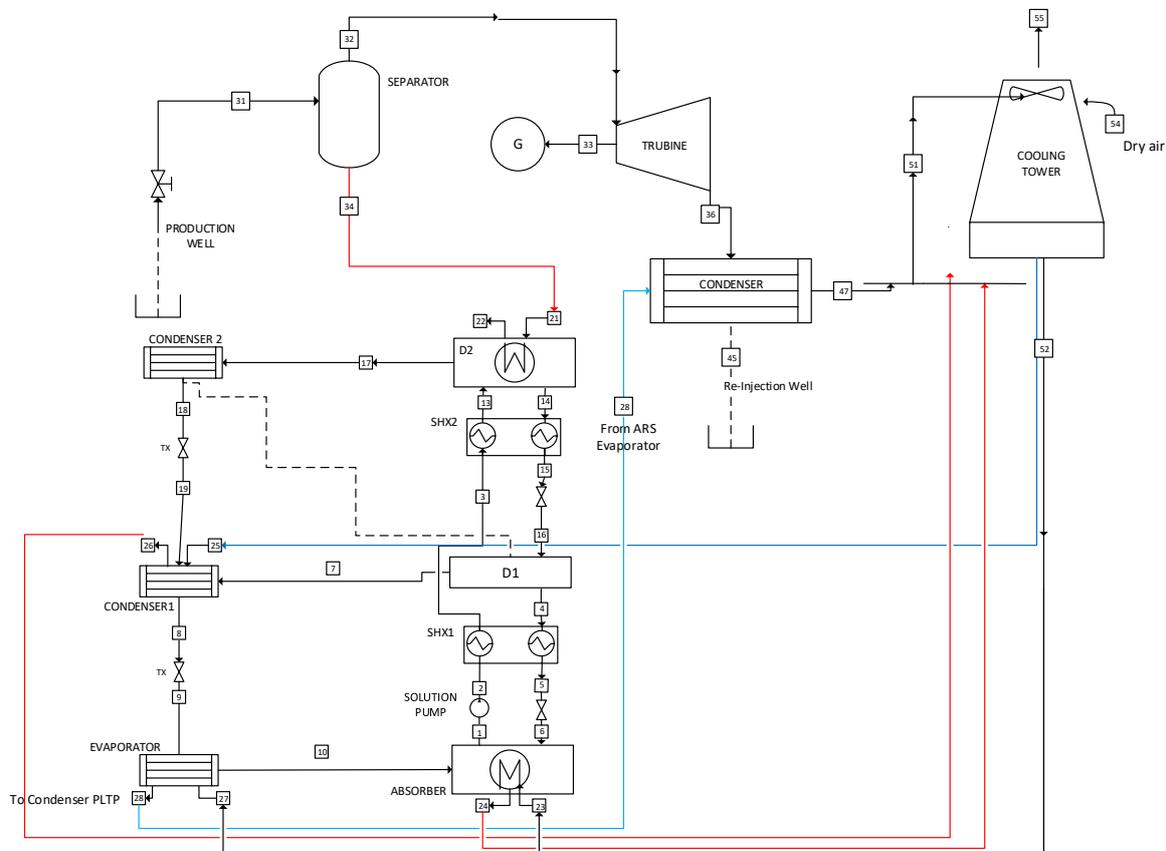


Figure 1. Schematic System of GPP and absorption refrigeration system.

The performance of the power plant is very dependent on the performance of the condenser to condense the steam from turbine output [12], the lower pressure on the condenser means more power to be produced by turbine, this is due to the large difference of enthalpy. This results in an enthalpy difference that reduces power generation results. Under these circumstances further cooling systems are required to lower the cooling water temperature. In this research, we are trying to use double effect absorption to reduce cooling water from cooling tower before it goes to power plant condenser for steam condensation process.

All the components in this system can be treated as control volume and the GPP-ARS is modeled on mass and energy conservation. Some assumptions are made as follows to simplify the mathematical model:

- (1) Potential and kinetic energy change during the heat exchange and at all fluid streams are ignored.
- (2) Heat exchanger is well insulated from the surroundings; that means heat exchange only occurs between hot and cold stream.
- (3) The working fluid at absorber, condenser I and condenser II outlet is saturated liquid.
- (4) The flows across the throttle valve are isenthalpic.

3. Mathematical models

Thermo economics which a combine concepts of both exergy and economic is a relatively new object in engineering. In exergoeconomic analysis, the cost of thermodynamic inefficiencies is integrated in the cost of products of the system [13-15]. Thermo economics reveals the cost formation process in energy systems which enables engineer to design cost effective systems [16].

3.1. Energy and exergy analysis

To simulate and analyse the thermodynamic performance of the proposed system, a code is developed in Engineering Equation Solver (EES) software. Each system treated as control volume which the mass and energy conservation as well as the principles of second thermodynamics law are applied.

The first law consists of mass, concentration and energy balance at each component of the combined system, while second law analysis deals with exergy destruction of the system components and exergetic efficiency of the system [12].

Mass balance

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \quad (1)$$

Energy balance

$$\dot{Q} - \dot{W} = \sum_{out} \dot{m} \cdot h - \sum_{in} \dot{m} \cdot h \quad (2)$$

Exergy balance

$$\dot{X}_{des} = \sum_{out} \left(1 - \frac{T_{amb}}{T_j}\right) \dot{Q}_j - \sum_{in} \dot{m} \cdot E_x - \sum_{out} \dot{m} \cdot E_x \quad (3)$$

Exergy rate

$$\dot{E}_{x,n} = \dot{m}(h - h_o - T_o(s - s_o)) \quad (4)$$

In this research, double effect absorption using two different working fluids, water as refrigerant and lithium bromide as absorber. The initial design parameter for double effect absorption listed as follows : $T_{21}=173.5^\circ\text{C}$, $T_{\text{evap}}=5^\circ\text{C}$, $T_{\text{cond}}=35^\circ\text{C}$, $T_{\text{des}}=120^\circ\text{C}$, $T_{\text{abs}}=32^\circ\text{C}$, $n_{\text{shx}}=0.7$, $T_{\text{cw}}=26^\circ\text{C}$

The requirement of the heat exchanger area for the absorption system was calculated using the log mean temperature difference (LMTD) method [17]. Since rate of heat transferred is a linear function of the overall coefficient of heat transfer, the heat transfer area of the heat exchanger and the LMTD, for the heat transfer process could be derived from equation (8). The heat exchanger area then used to calculate the annual cost for this refrigeration system.

$$Q = U \cdot A \cdot LMTD \quad (5)$$

Table 1. Overall coefficient of heat transfer (U) value for each components [3].

Heat Exchanger	Type	U[kW/m ² C]
Absorber	Shell & tube	0.85
SHX	Plate	1.1
Desorber	Shell & tube	0.85
Condenser	Shell & tube	1.4
Evaporator	Shell & tube	1.5

3.2. Mathematical model validation for energy and exergy analysis

To verify the validity of the mathematical model, the available data in literature serves as contrast to the simulation results. The absorption refrigeration cycle are validated by data in Ref. [11]

3.3. Economics and cost analysis

The cost system in this research is considered as investment cost. Investment cost can be calculated by sum of each investment cost for each component of the system, scrubber, turbine, condenser, cooling tower, desorber, absorber, evaporator, and solution heat exchanger. The general equation for economic analysis [18-20]:

$$C_E = C_B \left(\frac{Q}{Q_B}\right)^M \quad (6)$$

Table 2. Constant C_B and M value for each components.

Component	Market Price (\$) [C_B]	M Constant
Scrubber	4920 USD (0.1 m ³)	0.53
Turbine	13 million USD (30MW)	0.6
Condenser	-	-
Cooling Tower	4430 USD (10 m ³ /h)	0.63
Absorber	16500 USD (100 m ²)	0.6
Solution heat exchanger	12000 USD (100 m ²)	0.6
Desorber	17500 USD (100 m ²)	0.6
Condenser ARS	8000 (100 m ²)	0.6
Evaporator	16000 (100 m ²)	0.6

The capital recovery factor (CRF) equation can be written as

$$CRF = \frac{i(1+i)^n}{((1+i)^n)-1} \quad (7)$$

In evaluating and optimizing energy systems' performance, minimization of the annual cost of output power is an important objective [17]. In the present study, this parameter is selected as the objective function on which the system performance is optimized. All the capital investment included in this parameter which is defined as [21]:

$$C_{tot} = (C_{sep} + C_{tur} + C_{con} + C_{ARS}) \cdot CRF \quad (8)$$

4. Result and discussion

In this section the process optimization on GPP and Absorption refrigeration system will be displayed. The operation parameters of multi objective function and ranges of key thermodynamic parameters are listed at table 3.

Table 3. Operation parameters for optimization.

Term	Value
Population size	50
Ranges of throttle valve pressure	400 – 900 kPa
Ranges of absorber temperature	30-35 °C
Ranges of desorber temperature	120-140 °C
Ranges of condenser temperature	30-40 °C
Ranges of evaporator temperature	3-16 °C

Table 3 shows the range values of thermodynamic parameters used for optimization. Which has lower and upper bound. The results of multiobjective optimization are shown in table 4.

Table 4. Multi objective optimization results.

Term	Value
Throttle valve pressure	779.11 kPa
Absorber temperature	32.98 °C
Desorber temperature	121.13 °C
Condenser temperature	37.26 °C

Evaporator temperature	11.1 °C
Total exergy destruction	34257 W
Cost	73156.83 \$

Multi-objective optimization needed to know what value of parameters that will give the optimum value for both objective function [6]. Figure 2 shown the graphic of multiobjective optimization as the result from MATLAB multiobjective optimization. The graphic called pareto front and every dot on that graphic represent optimum value. In order to find the optimum value with two objective function, multicriteria selection method used [21]. In this study, two variables are exergy destruction and cost as consideration of multi objective optimization. When exergy values rise from 3.4 MW to 3.45 MW, there is a decrease amount of the cost. The best economic performance occurs at point B where the exergy value is 3.44 MW with lowest cost 72243.6 \$. While the maximum thermodynamics performance occurs at point A 3.4 MW with the highest annual cost 74608.9 \$. It's clearly seen that multiobjective is needed to find the optimum value between exergy destruction and annual cost. Finally with TOPSIS method, the optimum thermodynamic performance occurs at 3.42 MW exergy value with a cost value 73156.8 \$.

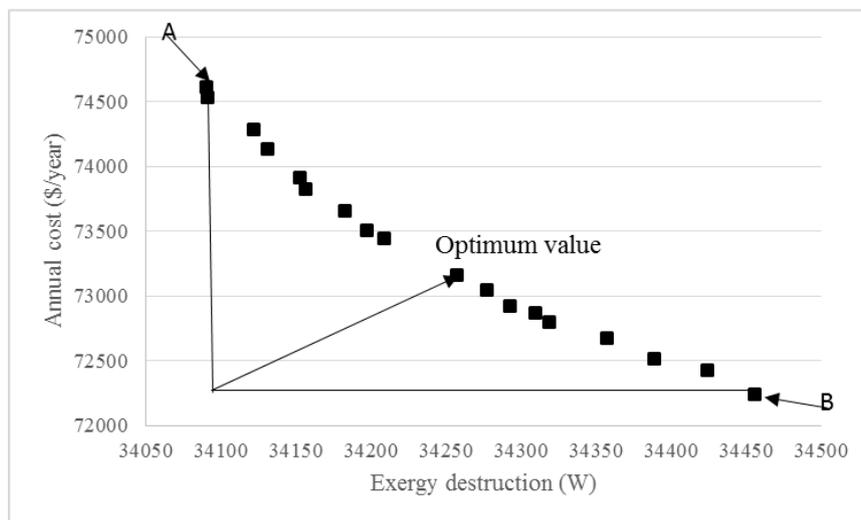


Figure 2. Distribution of the Pareto optimal solutions for Exergy Destruction and Specific Cost.

5. Conclusion

In this study, the thermodynamic & economic analysis for implementation of absorption refrigeration system to the Ulubelu GPP was simulated by using MATLAB-EES to obtain optimum value. Thermodynamic and exergoeconomic models were developed on EES to analyze the performance of such systems. Multi-objective optimization by MATLAB optimtool used to determine the optimum value of thermodynamic and exergoeconomic value of a system using 5 decision variables; throttle valve pressure, temperature of absorber, condenser, desorber and evaporator on absorption. The results showed that the optimum throttle valve pressure occurred at 779.11 kPa, temperature of absorber at 32.98°C, desorber at 121.13°C, condenser at 37.26 °C and evaporator at 11.1°C. with those optimum values, the system yield 34257 W of exergy destruction and annual cost of 73156.83 \$/year.

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