Thermodynamic analysis and multi objective optimization of kalina and absorption cycle for power and cooling driven by lahendong geothermal source

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Abstract. Kalina cycle is a new concept in thermodynamics that convert heat energy into mechanical energy. The heat source in this system comes from the Lahendong geothermal source. The cycle is using a mixture of solution of two liquids with different boiling points for the working fluid. Water and ammonia are the most widely used combinations with a 30% - 70% ratio in this study. With the combined benefits of comparison ratios, the Kalina cycle is able to produce better exergy efficiency and exergoeconomoic compared to conventional Rankine cycle. Kalina cycle works on thermal efficiency around 40% - 60%. The objective of this study is to find optimization in exergy efficiency and exergoeconomic based on Kalina cycle applied in Lahendong geothermal source used MATLAB-EES. The results showed that the optimal ammonia-water mixture occurred at 130.0626 °C, 2184.791 kPa, and 51.77% of basic solution can yield exergy value 2358.88517 W and use the cost 16994.9715 $/year.

1. Introduction
Indonesia is one of the world’s largest geothermal energy sources. With the increasing demand for electricity occurs in Indonesia each year requires additional capacity to produce electricity in accordance with national electricity consumption. Although Indonesia is one of the largest geothermal energy producers, its development is relatively slow and has many difficulties. Over the span of 20 years, Indonesia is only able to develop at least 807 MW or about 4 percent of the 20,000 MW of availability geothermal source [1].

Geothermal energy has its own challenges in its development. Some of the factors that affect the inhibition of geothermal energy development in Indonesia are: the process of exploration resource was expensive and there is no market for resources other than as electricity producers. The cost locating and verifying a new source for geothermal power projects is high, this phase is similar to the discovery of oil fields or coal mines. Geothermal energy is specific and must be converted into electricity around the energy source [2].

In 1984, Alexander Kalina discovered a power plant cycle using geothermal power with low to medium temperatures as a thermodynamic cycle [3]. The kalina cycle uses a mixture of water – ammonia as its working fluid. Water-ammonia are widely used as working fluids in the cycles because of their excellent thermodynamics to transfer heat. The kalina cycle has the potential to efficiently convert energy from the
source of thermal energy. At the low and medium temperature of geothermal energy, the utilization of the Kalina cycle produces a satisfactory thermodynamic performance.

In addition to kalina cycle, The cooling absorption cycle with water-ammonia is also expected to provide an important role in heat source recovery. Some researchers conducted energy and exergy analyze for cooling the absorption of water and ammonia mixtures and found the optimum temperature of the cultivated sources to maximize the coefficient of performance (COP) [4, 5].

Currently, the merger between the cooling and power cycle is becoming a widely used technology for energy efficient utilization. The reason to use kalina cycle is for improving the efficiency of absorption cooling system and power systems. In the kalina cycle, a low concentration of ammonia solution is extracted to the separator at high temperature. This study aims to utilize the heat contained in a low concentration of water-ammonia solution. Thus, the cooling absorption cycle inserted to the kalina cycle before the high temperature recuperator to produce simultaneous power and cooling output. The research in this paper is the first discusses the optimization multi objective from exergy destruction and cost in combined kalina and absorption cycle.

2. Description System
The kalina cycle in this study consist of several components part, namely: HRSG, Separator, Turbine, Generator, High Temperature Recuperator (HTR), Low Temperature Recuperator (LTR), Condenser, Pump, Throttle Valve, and Refrigeration Cycle Absorption. in this refrigeration section, the component parts are pre-cooler, condenser, SHX, Distillation Tower, throttle valve, pump, and evaporator. The schematic diagram as shown in figure 1.

After being heated at evaporator where heat is extracted from geothermal well, an ammonia-water mixture flows towards the separator and then separates into ammonia-rich vapor and ammonia-poor solution in separator. Ammonia-rich vapor with high content of 96% and mixture of ammonia with low levels of 49%. This ammonia-rich vapor will flow into the turbine and the rotate the generator, while the ammonia-low solution which still has a relatively high temperature and mass flow rate is used as a heat source to heat distillation tower in the absorption refrigerant cycle in state, 40% ammonia solution is cooled back to the HTR and flowed to throttle valve 1 for reduced pressure.

![Figure 1. Schematic System of Kalina Cycle](image)
After being used at turbine and absorption refrigerant cycle, ammonia-rich vapor and ammonia-poor solution will be re-mixed at state 7 to state 8 in the ammonia-water solution phase. The ammonia-water solution is then cooled by the LTR and condenser 1, temperature and pressure of ammonia-water solution will reduce on state 10. Then ammonia-water solution pressure will be raised by the pump 1. The compressed ammonia-water solution will absorb heat in the LTR and HTR and will return to state 13 and back to evaporator again to repeat the cycle.

In the absorption refrigerant cycle, the strong ammonia solution is pumped through SHX to distillation tower. The strong solution is heated by ammonia-poor solution in distillation tower and purified into refrigerant with high concentration [6]. High concentration refrigerant is condensed in condenser II, temperature and pressure at state 17 drops significantly after passes through the pre-cooler and throttle valve 3 to drops the pressure and temperature. Then back to pre-cooler and into absorber. The ammonia weak solution at distillation tower is cooled with cooling water at SHX flowed to the absorber and mixed with a strong ammonia solution. From absorber this mixed is pumped to distillation tower. This process occurs continuously (looping) in the cycle of refrigerant absorption.

3. Exergoeconomics Analysis
Exergoeconomics in which the concepts of exergy and economic have been combined is a relatively new area in engineering. In exergoeconomic analysis, the cost of thermodynamic inefficiencies is integrated in the cost of products of the system [7, 8]. Exergoeconomics reveals the cost formation process in energy systems which enables designer to design cost effective systems [9]. In economic analysis the prediction of the capital investment cost is important. In this respect, consulting with cost engineers or using vendor quotations is probably the most accurate method. In consulting with cost engineers to determine the new purchased equipment costs after each design modification, the necessary thermodynamic data is submitted to the cost engineer. But generally the cost functions available in the literature are used for determining the capital investment cost of components in exergoeconomic analysis of a system. The cost values calculated from the cost functions are in agreement with the corresponding values provided by the cost engineer. It should be taken into account that in exergoeconomic analysis, if first, the values obtained for the capital cost of the components through the intended cost function are very different from the actual purchased equipment costs in different sizes of components and second, inflation rate, interest rate and other economic parameters vary extensively during the lifetime of the system, the results obtained from exergoeconomic analysis will be very different from the practical results certainly. Perhaps the fundamental limitation of the theory of exergetic cost, as it was originally formulated, consisted of defining the productive structure in relation to the same flows and components presented in the physical structure. The resulting difficulties lie mainly in the adequate treatment of the dissipative units and of the residues of the system. Another difficulty is to identify the useful products of the system units as co-products or products-sub products. In recent years, many exergoeconomic studies have been conducted for different energy systems [10-18].

3.1. Energy and exergy analysis
The Kalina-based CCP cycle will be analyzed from energy and exergy perspective. Energy analysis based on the first law of thermodynamic discusses the energy conversion in quantity, but it is incapable of indicating the work potential or quality of different energy forms in relation to a given ambient condition [19]. Exergy method not only demonstrates the amount of usable work potential, or exergy, supplied as input to a system, but also reveals the system irreversibility distribution among different components and pinpoints the one contributing most to overall system inefficiency.
3.2. Validation for energy and exergy analysis
To verify the validity of exergy analysis, the available data in literature serves as contrast to the simulation results. The Kalina cycle and absorption refrigeration cycle are validated by data in Ref. [21] and Ref. [8], respectively. The Kalina cycle has the similar schematic diagram as illustrated in figure 1. When refrigeration cycle isn’t attached to Kalina cycle, state 3 and state 5 are the same point. Therefore, all node numbers of Kalina cycle is in conformity with those in figure 1 and state 3 and state 5 share the same thermodynamic parameters.

3.3. Economics and cost analysis
For exergoeconomic analysis different methodologies have been developed in recent years, among which the specific exergy costing theory (SPECO) has been widely applied to investigate thermodynamic cycles. This method establishes a rational technique to assess the cost rates of exergy streams by which the specific cost of each exergy stream (including the system products) can be evaluated. To perform an exergoeconomic analysis using the SPECO method, a cost balance equation along with required number of auxiliary relations, are applied to each system component [22-26].

In evaluating and optimizing energy system’s performance, minimization of the specific cost of output power is an important objective [11, 27]. In the present study, this parameter is selected as the objective function on which the system performance is optimized. All the capital investment, operation and maintenance and fuel costs are included in this parameter [11].

4. Result and Discussion
In this section the process optimization on Kalina cycle driven by Lahendong geothermal reservoir will be displayed. The operation parameters of multi objective function and ranges of key thermodynamic parameters are listed at table 1.

| Term                  | Value          |
|-----------------------|----------------|
| Population size       | 100            |
| Generation            | 100            |
| Ranges of expander inlet pressure | 1600 – 4000 kPa |
| Ranges of expander inlet temperature | 130-180˚C       |
| Ranges of concentration of basic solution | 50-80%         |

Table 1 shows the values of thermodynamic parameters conditioned on the turbine’s capability. Then the results of optimization Kalina cycle are shown in table 2.

| Term                  | Value          |
|-----------------------|----------------|
| Expander inlet pressure | 2184.791 kPa   |
| Turbine inlet temperature | 130.0626 °C   |
| Concentration of basic solution | 51.7 %         |
| Exergy destruction at turbine | 2.35 kW      |
| Cost                  | 16994.9715 $   |

Table 2. Optimization results

In this study, two variables are exergy destruction and cost as consideration of multi objective optimization. Fig.2 shows the proposed pareto front solution for ammonia-water mixture as the working fluid of Kalina combine cycle. Each point in this pareto distribution illustrates relationship between two
objective functions. When exergy values rise from 1.7 kW to 2 kW, there is a decrease amount of the cost. The optimum thermodynamic performance occurs at 2.3 kW exergy value with a cost value 16.9k $. The best economic performance occurs at point B where the exergy value is 3.1 kW with lowest cost 16 kW.it seen that’s point A and B shown each objective function for cost and exergy value. The ideal solution in this multi-objective problem is to illustrate all points on the pareto distribution, then the final optimal point is determined.

![Figure 2](image.png)

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

5. **Conclusion**
In this study, the analysis for kalina-based ccp cycles heated by Lahendong geothermal reservoirs was analyzed, considering the differences temperature and pressure on the wellhead. MATLAB-EES is used to obtain optimum value. Thermodynamic and exergoeconomic models were developed to analyze the performance of such systems. Multi-objective optimization is calculated to determine the optimum value of thermodynamic and exergoeconomic value of a system using optimization parameters of turbine, turbine inlet pressure, turbine inlet temperature, concentration of ammonia-water basic solution. The results showed that the optimal ammonia-water mixture occurred at 130.0626 °C, 2184.791 kPa, and 51.77% of basic solution can yield exergy value 2358.88517 W and use the cost 16994.9715 $/year.

6. **Acknowledgment**
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