Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

THERMODYNAMICS ANALYSIS OF KALINA CYCLE SYSTEM (KCS) 11 FOR JAILOLO GEOTHERMAL FIELD – HALMAHERA

[1]Yose Ardhani Farasi, [2]Sihana, [3]Khasani, [4]Deny Kurniawan

[1,2] Department of Nuclear Engineering and Engineering Physics, Universitas Gadjah Mada
[3]Department Industrial and Mechanical Engineering, Universitas Gadjah Mada
[4]Star Energy Geothermal (WayangWindu) Limited.

[1]yose.farasi@gmail.com
[2]sihana@ugm.ac.id
[3]khasani@ugm.ac.id
[4]deny.kurniawan@starenergy.co.id

Keywords: KCS 11, Ammonia-water mixture, thermodynamics analysis, Cycle Tempo

ABSTRACT

Jailolo geothermal field located in western Halmahera will be developed geothermal powerplant to meet the electricity demand in Northern Maluku. The geothermal fluid is estimated to have the characteristics of two-phase medium temperature-water dominated with brine fractions of 80% (temperature 179 0C), possibly for a binary power plant development.

Kalina cycle system (KCS) 11 is a binary cycle which utilizes the thermodynamic properties of ammonia-water mixture, commercially built first in 2000 in Iceland and has proven success in operations by gaining better efficiency than other powerplant at low operating temperatures. This cycle is good for medium-enthalpy geothermal development.

Thermodynamic analysis that will be examined in this study to obtain optimum conditions in the Jailolo geothermal field based on calculations of energy with the help of software cycle tempo 5.0. To obtain maximum power and efficiency of the resulting system, optimization process is carried out on a mass fraction of ammonia-water mixture and turbine inlet pressure.

The optimum conditions obtained in mass fraction 85% of ammonia-water mixture with the turbine inlet pressure of 29 bar which has energy efficiency (net) 11.7 % with delivered net power 3.3 MW. This analysis can be considered to assist in determining of geothermal field development strategy in Jailolo.

1. INTRODUCTION

Electricity is the most important thing in human life. Electricity needs in the world will increase in accordance with the growth of the number of people, while the available natural resources are limited. PT PLN (Persero) estimates that national energy needs in 2022 will reach 386 Terawatthour (TWh), or an average growth of 8.4 % per year with eastern Indonesia a first priority.

At now the fulfillment of electricity needs in eastern Indonesia is a still dependent on the supply of diesel power plants, where the cost of generation is increasingly high along with the continued increase in fuel prices. On other hand, eastern Indonesia has the geothermal energy potential which can be used as electricity.

One of the geothermal energy potentials in eastern Indonesia is Jailolo geothermal field, Halmahera. The results of feasibility study, Jailolo geothermal field is estimated can be utilized as 50 MW of electricity [1].

In the geothermal energy utilization into electricity, the type of energy conversion technology commonly used is dry steam, flash system, binary cycle and combine cycle [2]. Geothermal development need selection of the right type of energy conversion technology so that its utilization can provide optimum results both in terms of thermodynamics and economics.

The Kalina cycle system (KCS) 11 is one of the binary cycles which is an electric power cycle that utilizes the thermodynamic properties of ammonia and water or can also be called ammonia-water mixture. This cycle was the first commercially available in the world in 2000 in Iceland and has proven success in operations and has better efficiency than other power plants operating in low temperatures. [3].

The purpose of this study is to obtain the optimal cycle configuration from the initial conditions and energy analysis of the Kalina cycle system. Optimizing the system will increase efficiency and produce optimal power.

2. METHODOLOGY

This study uses secondary data that is estimation curve "well deliverability", air quality, and water quality on the Jailolo geothermal field. The air quality around the Jailolo geothermal field ranges from 29 – 31.3 °C, while the water quality is 26.3 °C [1].

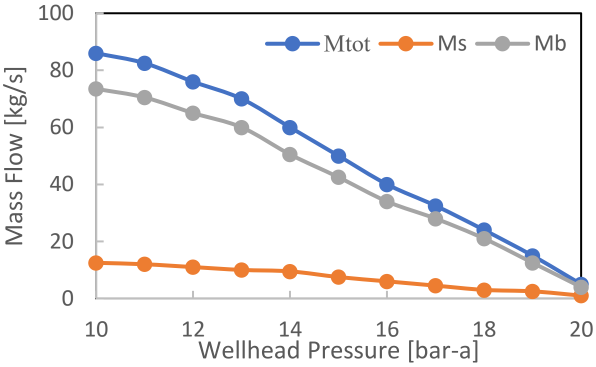

Figure 1: Well deliverability Curve

This study uses ASUS A455L Laptop intel Core CPU i5-5200U 2.2 GHz CPU 4 GB memory with operating system Windows 10 Student Version 64-bit. This study also uses Cycle Tempo 5.0, Simulis, and Microsoft Excel 2013.

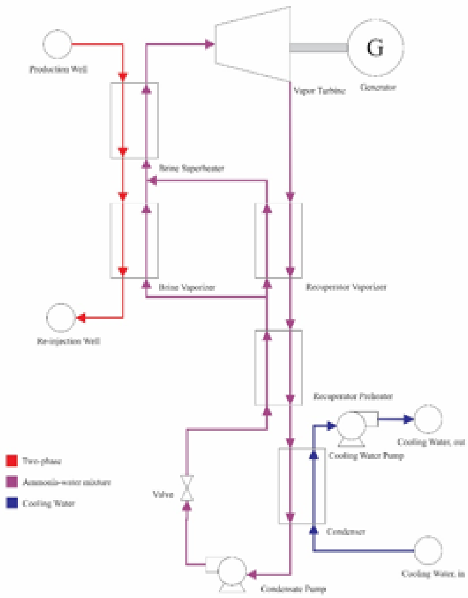

Figure 2: Kalina Cycle System (KCS) 11 design

The stages to be carried out in the analysis process are determining input data and assumptions needed, including geothermal fluid data, power plant design, environmental data (air quality and water quality). Then using Cycle Tempo for modeling and determine the optimum cycle by varying the turbine inlet pressure and the ammonia-water mixture mass fraction with a reinjection temperature of ≥ 90 °C to produce maximum net power. Finally, analyzing the optimum cycle obtained and determined thermal efficiency.

3. DISCUSSION

3.1 Wellhead pressure optimization

Determination of optimum pressure is done by simulating by entering the value of pressure and certain mass fractions varied by the condition of WHP. The WHP curve shows that the greater the wellhead pressure, the smaller the velocity of mass flow. This is because the greater the pressure of the wellhead the smaller the production of the brine produced so that the speed of the brine flow will also be smaller, where the wellhead pressure is inversely proportional to the speed of the brine flow.

In accordance with Figure 3 by using cycle tempo simulation, 30 bar turbine inlet pressure was used as initial data, it was found that WHP produced the largest power at pressure and mass flow of 10 bar and 73.5 kg/s. In the subsequent analysis, a 10 bar-a WHP pressure and a 73.5 kg/s brine mass flow were used by varying the turbine intake pressure on the ammonia-water mass fraction. The maximum power value obtained in the ammonia-water mixture is 85%. Then for each ammonia-water mixture mass fraction the value of optimization will be sought by varying the turbine inlet pressure in each mass fraction. Where is the value of the turbine intake pressure range at a pressure of 28-35 bar.

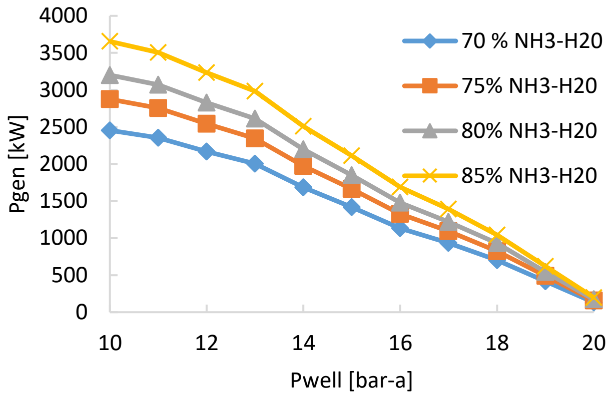

Figure 3: Power output curve

3.2 Analysis of Kalina Cycle System modelling

Modeling of the power generation is carried out in a Cycle Tempo based on the Kalina Cycle System (KCS) 11. The process of modeling is started by inserting the working fluid of ammonia-water with a mass fraction of 70% and a pressure of 30 bar, the fluid in the mixed phase will be changed with brine superheater to superheat before entering the turbine. With the temperature difference between the steam entering and the working fluid comes out at 10 °C on the brine superheater. Then from the brine superheater the working fluid that has become vapor phase with a superheat state is flowed into the turbine with an isentropic efficiency input of 80%. Exiting the working fluid turbine is used s the recuperator vaporizer heating fluid and the preheater recuperator to heat the ammonia-water liquid phase out of the condenser. The input of the fluid pressure outlet the turbine apparatus follows the smallest possible output pressure, which indicated by no warning on the simulation. The outlet pressure on this turbine is 11 bar.

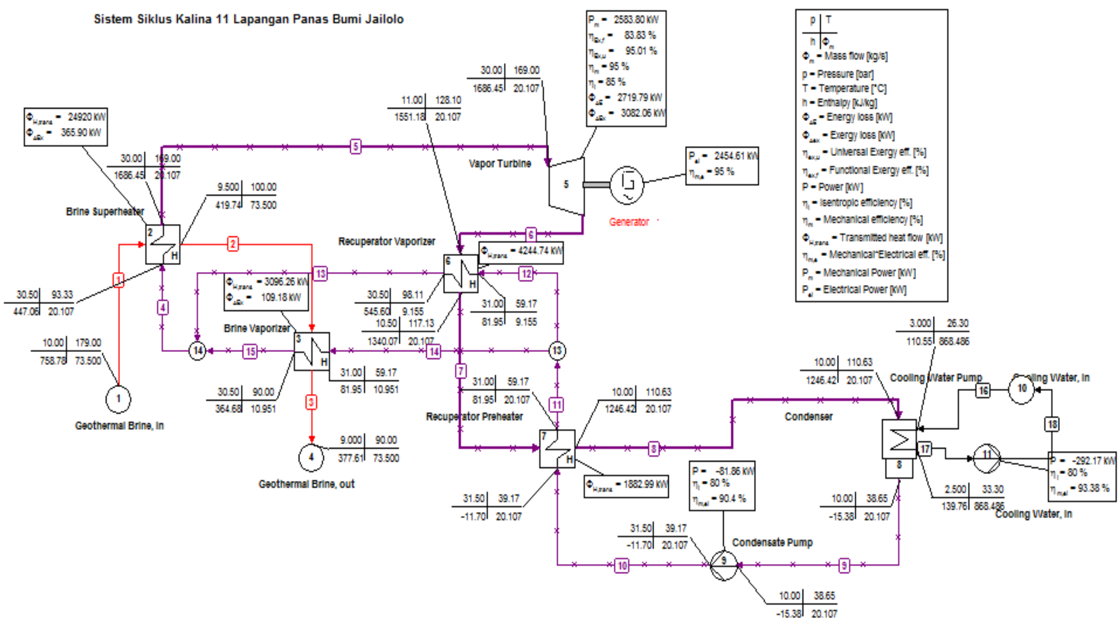

Figure 4. Kalina cycle system 11 modeling on Cycle Tempo

From these data, a comparison between the power produced and the power resource used is obtained. The amount of power utilized by the Kalina cycle system is 24,919.44 kW derived from brine superheater and brine vaporizer, while the power produced by the Kalina cycle system is 2080.58 kW. From the simulation results of the Kalina cycle system modeling at pressure 30 bar with mass fraction of 70% ammonia-water mixture can be displayed in the Q-T diagram for heat exchanger components.

Figure 5 shows a Q-T diagram on a brine superheater, brine vaporizer, recuperator vaporizer, and recuperator preheater. The recuperator vaporizer component and the recuperator preheater are not flowed by brine. In the Q-T diagram the top line views from left to right. It is the heat source of brine used to het the ammonia-water mixture. Out of the heat exchanger the brine temperature has decreased, where the brine vaporizer exit temperature is maintained at a temperature of 90 °C to avoid silica scaling.

The bottom line is a working fluid line, ammonia-water which has an increase in temperature, in the evaporation process changes in the chemical composition of liquid or vapor.

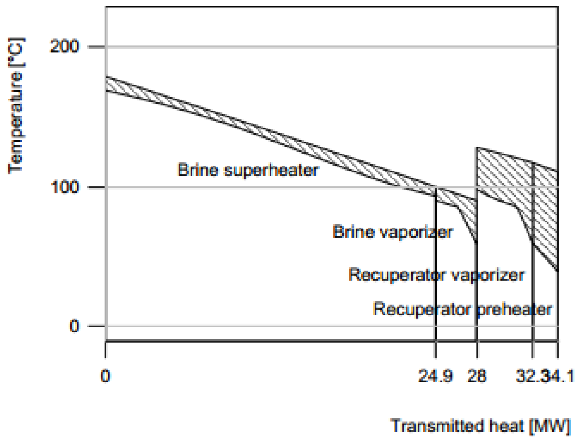

Figure 1: Q-T Diagram

3.3 Analysis of variations in turbine inlet pressure

3.3.1 Analysis of turbine inlet pressure variations on 70% ammonia mass fraction

In the 70% ammonia-water mass fraction with a pressure of 28 bar, the Kalina cycle was able to produce power of 2577.65 kW with up to 90.8% quality. The effect of pressure on the quality of steam out of the turbine and the power produced can be known by varying the turbine inlet in the mass fraction of 70%.

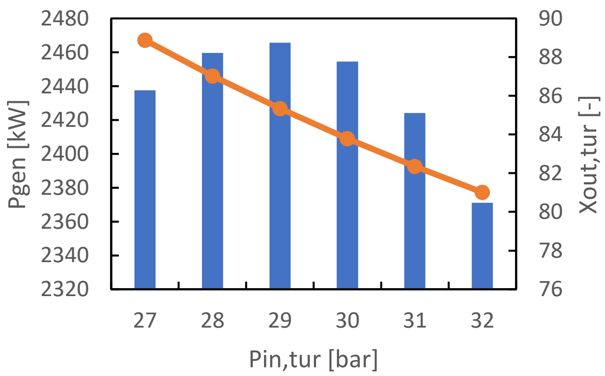

Figure 6: 70% ammonia-water mixture

Figure 6 shows the effect of turbine inlet pressure on the mass fraction of 70% on the power produced and the quality of the turbine inlet pressure. Figure 6 shows that the greater the turbine inlet pressure, the lower the quality of the steam out of the turbine. Increased turbine inlet pressure is not followed by an increase in power generation. The six variations turbine inlet pressure there is a maximum power produced, which is at the 29 bar turbine inlet pressure which power produces of 2465.73 kW. Whereas at pressures greater than 30 bar, the power produced actually decreases. At the pressire above 32 bar there is an error where this error is caused by negative mass flow value at the condensate pump output, so that the pressure variation is only carried out by a 32 bar turbine inlet pressure.

In 70% ammonia-water mass fraction, the quality of the inlet steam is not 100%. But at 27 bar and 28 bar, the turbine inlet has vapor quality is ≥ 90, but at the outlet temperature the turbine is between 81-88% so that in the mixed mass fraction 70% can not be used vapor turbine back pressure type.

3.3.2 Analysis of turbine inlet pressure variations on 75% ammonia mass fraction

At 75% mass fraction with 29 bar turbine inlet pressure, Kalina cycle is able to power produced 2939.53 kW with turbine inlet and outlet steam quality of 98.46 and 93.43%. The influence of the turbine inlet pressure and the resulting power can be known by varying the pressure of the turbine inlet pressure on the mass fraction of 75%.

Figure 7 shows the effect of turbine inlet pressure on the mass fraction of 75% in the power produced and the steam quality coming out of the turbine. Figure 7 shows that the greater the turbine inlet pressure, the lower the steam quality out of the turbine. The increase in turbine inlet pressure is not followed by an increase in power generation. From all the turbine inlet pressure variations there are the maximum power produced, which is 31 bar turbine inlet pressure which power produced of 2877.66 kW with steam quality of the inlet turbine at 95.12 and the steam quality outlet at 90.3%. Whereas in the turbine inlet pressure greater than 31 bar the resulting power decreases. From this variation the lowest turbine inlet pressure power produced at 35 bar turbine inlet pressure, with steam power and quality of 1881.14 kW and 89%

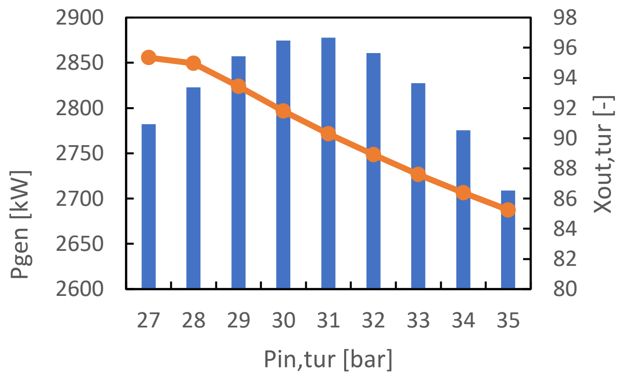

Figure 7: 75% ammonia-water mixture

3.3.3 Analysis of turbine inlet pressure variations on 80% ammonia mass fraction

At 80% mass fraction with 80 bar turbine inlet pressure, the Kalina cycle is capable of power produced of 3171.19 kW with steam inlet and outlet turbine quality of 100% and 96.32%. The influence of the turbine inlet and the resulting power can be known by varying the pressure of the turbine inlet pressure on the mass fraction of 80%.

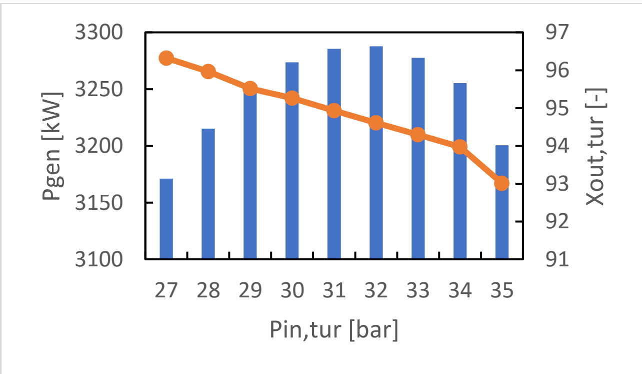

Figure 8: 80% ammonia-water mixture

In the ammoni mass fraction 80% of the steam quality inlet turbine is 100% steam. The 8 variations of pressure there is a maximum power at pressure of 32 bar with the power produced is 3287.77 kW

3.3.4 Analysis of turbine inlet pressure variations on 85% ammonia mass fraction

In a mass fraction of 85% the steam quality inlet turbine is 100% steam, at a pressure of 28 bar, the power produced is 3643.43 kW wth steam quality out of the turbine is 97.1%.

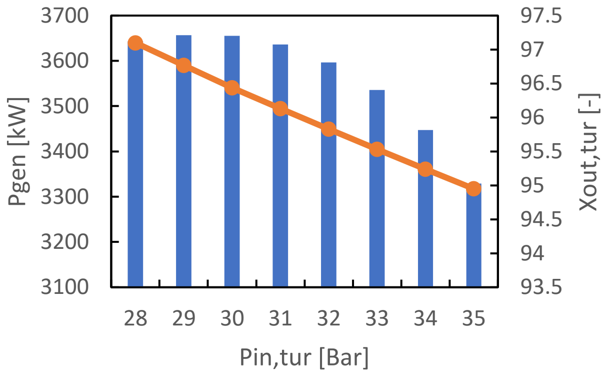

Figure 2**:** 85% ammonia-water mixture

Figures 9 shows from the 8 pressure variations there is maximum power that is at the pressure of 29 bar with the resulting power of 3656.78 kW.

<u>3.3.5 Relation between steam quality, mass fraction, and turbine inlet pressure</u>

From t-x diagram it can be seen that for a pressure of 30 bar, the mass fraction of ammonia-water 70 and 75% is in a condition of a mixture of liquid and steam. Whereas in the mass fraction of 80% and 85%, at a temperature of 169 0C the quality of the steam entering the turbine is 100% steam. In this graph by increasing or decreasing the pressure, the t-x diagram will shift up or down, affecting the quality of the steam entering and exiting the turbine at the same temperature. By increasing the pressure, the quality value of the steam entering the turbine will decrease, while by reducing the pressure, the quality value of the steam produced will increase at the same temperature. Whereas by increasing the fraction of ammonia-water mixture the curve will shift left or right, where with a smaller fraction of the mass the evaporation process occurs faster while the larger fraction of mass will take longer to evaporate

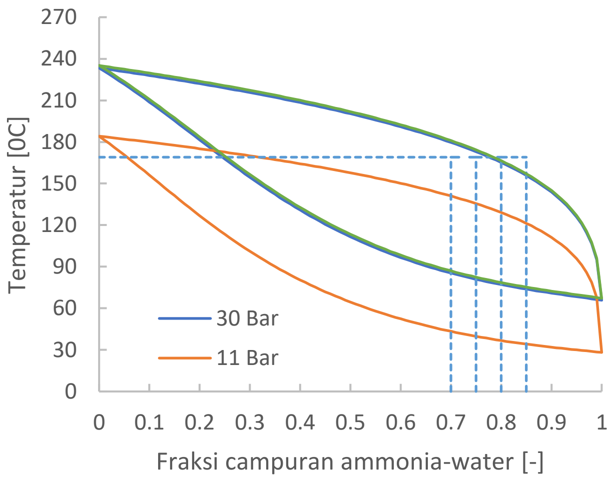

Figure 10: T-x diagram

3.4 System efficiency

In the concept of energy that applies the law of energy stickiness which says that energy cannot be destroyed and created but can move from one form to another. The exergy concept says that energy has a potential value that can be utilized or that has no work potential called anergy.

From the data presented above the absorbed power value of the brine water is constant, but the power value generated in each mass fraction and turbine inlet pressure is different.

In Figure 10. it can be seen that the net efficiency value increases with the increase of the ammonia-water mixture mass fraction. Each ammonia-water mass fraction has maximum net efficiency. In the mass fraction of 70% ammonia, it has a maximum efficiency of 7.5% at 29 bar turbine inlet pressure. 75% ammonia-water mass fraction has a maximum efficiency of 8.9% at 31 Bar turbine inlet pressure. 80% ammonia-water mass fraction, has a maximum efficiency of 10.3% at 32 bar turbine inlet pressure. Meanwhile, the mass fraction of 85% ammonia, has a maximum efficiency of 11.7% at 29 bar turbine inlet pressure.

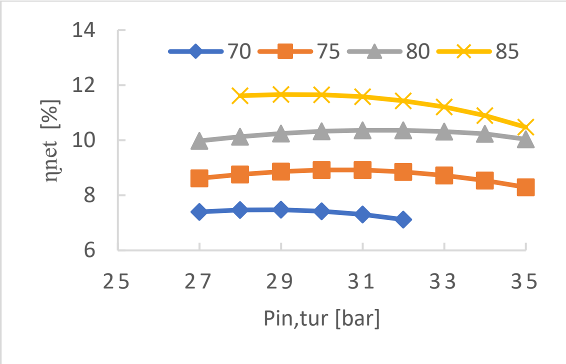

Figure 11: System efficiency vs turbine inlet pressure

This difference in efficiency value is caused by differences in the enthalpy value of the turbine that enters and also the mass flow of your cycle system. Where the difference in enthalpy values coming in and out of the turbine increases with the increase in turbine inlet pressure. But the greater the turbine inlet pressure, the smaller the velocity of mass flow in the working fluid pipe. This is because the greater the turbine inlet pressure, the production of the working fluid produced will be smaller so that the speed of fluid flow will also work smaller, where the turbine inlet pressure is inversely proportional to the flow velocity of the working fluid.

From the analysis on the KCS 11 system for the condition of the Jailolo geothermal field that has been described, it is important to provide guidance in choosing the composition of the mass fraction and optimal turbine inlet pressure. From the analysis shows that the mass fraction and turbine inlet pressure with the power value of the generator and energy efficiency and the consequences of the system are caused, the mass fraction of working fluid, ammonia water, 85% and 29 bar turbine inlet optimization pressure give the most satisfactory value

4. CONCLUSION

From the simulation and the results of the calculations carried out, conclusions can be obtained in the form of: 1) The Kalina cycle system KCS 11 which was tried to be implemented for the Jailolo - Halmahaera geothermal field condition turned out to produce electricity at a generator of 3 MW. 2) From the results of the analysis of the highest net power value and the highest energy efficiency obtained in the condition of 85% ammonia-water mixture configuration and 29 bar turbine inlet pressure, which is 3,303 MW. 3) The thermal efficiency of the KCS 11 system with a source of brine water 179 0C and a flow rate of 76.3 kg / s around 7% -11%.

5. BIBLIOGRAPHY

1] AECOM USA, Inc, “Fesibility Study for the Jailolo Geothermal Power Project in Halmahera Indones.” Aug-2012.

[2] R. DiPippo, Geothermal power plants: principles, application, case studies and environmental impact. Butterwoth-Heinemann, 2012.

[3] R. Maack and P. Valdimarsson, “Operating experience with Kalina power plants,” Geothermische Stromerzeug. Pstdam, pp. 17–18, Oktober 2002.

[4] “Data potensi panas bumi per pulau,” Pusdatin ESDM, 2012. [Online]. Available: kip.esdm.go.id/pusdatin.

[5] PT PLN (Persero), Rencana Usaha Penyediaan Tenaga Listrik PT PLN (Persero) 2013-2022. 2013.

[6] M. Mirolli, “Commercialization of The Kalina Cycle for Power Generation and ITs Potential Impact on C02 Emissions,” Exergy Inc, 2001.

[7] X. Zhang, M. He, and Y. Zhang, “A review of research on the Kalina Cycle,” Renew. Sustain. Energy Rev.

[8] S. Macwan, “The Kalina Cycle A Major Breakthrough in Efficient Heat to Power Generation,” presented at the WHP2013 Conference and Trade Show, 2013.

[9] P. VAldimarsson, “Geothermal Power Plant Cycles and Main Component,” UNU-GTP, 2011