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Techno-Economic Study of Binary Power Plant Application for Brine Heat Recovery in "X" Geothermal Field Indonesia

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Abstract

Geothermal field in "x"field in Indonesia producing wet steam that contain hot brine as result of separation from wet steam. Currently hot brine production is injected to injection wells. The need to extract the heat from hot brine had lead to further potential assessment of binary plant technology to extract the heat from hot brine into electricity.
In this paper process simulator used to get key parameters in binary power plant cycle. Around 12.8 MW of gross electricity could be produced from 953,400 kg/h of brine production. The research then proceed to economic feasibility using scheme of split as set forth under regulation of Government of Indonesia. How attractive the application from economic side under current scheme and feasible option of how to level up economic of similar project to attract investor are presented in this paper.

binary cycle, economic feasibility, energy utilization, hot brine, working fluid

I. INTRODUCTION

Table 1. State of The Art

No	*Project/Research*	*Design or Condition*
1	Lahendong	*Brine Condition*: 170^{0}C, 8.5 bar pressure. This Pilot project use water as indirect heating medium to absorb heat from hot brine and transfer it to isobutane as working fluid to produce ~ 0.5 MW.
2	Sarulla	*Brine Condition* : 210^{0}C, 20 bar separator pressure 2 System involved: • Brine GCCU (*Geothermal Combine Cycle Unit*). Using low pressure steam outlet from backpressure type turbine combine with low pressure hot brine • Hot brine energy extracted from separator at wellpad
3	Martina KopuniCova (Slovakia)	Comparison of ORC Vs *Kalina* working fluid
4	Wahyu Danumulyo ("X" field)	*Brine Condition*: 160^{0}C, 8.5 - 9 bar pressure. System involved: hot brine from almost all wellpads collected, transferred at 500 psig pressure and injected outside main reservoir area to avoid reservoir cooling. This initiative made brine heat recovery more feasible and will be studied in this paper using direct heating of working fluid from *hot brine*

Indonesian archipelago that located in pacific ring of fire have plenty resources of geothermal potential. Geothermal energy as one of the renewable energy resources expected to gain higher portion in full filling energy demand in Indonesia.

Indonesian Geothermal potential are estimated 40% of world geothermal resources with theoretical potential of around 30,000 MW. In the year of 2014, National Energy Committee set forth around 23% of total national electric power plant are coming from Geothermal resources in 2025 [1].

Geothermal field in X field of Indonesia is already in exploitation phase and produce electricity. Many island in Indonesia are lays in active volcano bed as ring of fire that have plenty active mountain and hills with indicative source of geothermal energy are emerge in kind of hot crater, hot spring.

Geothermal industry are competing with other source of energy (mainly from natural gas and coal fired power plant) and this challenging situation need full support and commitment from stakeholder as other kind of renewable energy are also emerging (wind, solar, ocean wave, biofuel, etc).

A. Field Condition

This "X" geothermal field currently producing steam to generate electricity using condensing steam turbine where the condensed steam in atmospheric pressure and low temperature (around 42^{0}C) are collected in condensate

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gathering system prior to be injected to injection wells.

Beside the low pressure and temperature condensate, the well production from this field dominantly flow in two phase to the wellhead and commonly known as wet steam. This wet steam produce hot brine resulted from separator in each well cluster that still have remarkable heat to be extracted. Currently all of the hot brine are entering brine gathering line and then injected directly to the injection wells using pump and gravity force. This hot brine which still have energy will be extracted in binary power plant to produce electricity.

B. Brine Properties

Majority of brine production which have temperature around 170^{0}C and at separator pressure in average of 125 psig then collected in the brine gathering line where it has to be increase the pressure up to 500 psig to enable to flow and entering injection well.

Brine properties from representative sample are taken and identified for its component and properties. The identification of this ion contents are important to know for further analysis of possibility of scaling deposition under flowing condition in the pipeline and all of the equipment. Brine mineralogy composition are shown in the table 2.

Table 2. Brine Properties and Mineralogy

No	Parameter	Value	Unit
1	Brine Rate	953,400	Kg/Hr
2	Pressure	500	Psia
3	Temperature	160	Celcius
4	PH	6.91	
5	TDS	20000	Mg/Kg
6	Sodium	5860	Mg/Kg
7	Potassium	1210	Mg/Kg
8	Calcium	510	Mg/kg
9	Magnesium	0.192	Mg/kg
10	Lithium	20.1	Mg/kg
11	Boron	420	Mg/kg
12	Silica	801	Mg/kg
13	Chloride	11100	Mg/kg
14	Sulfate	19.8	Mg/kg
15	Ammonia	3.76	Mg/kg

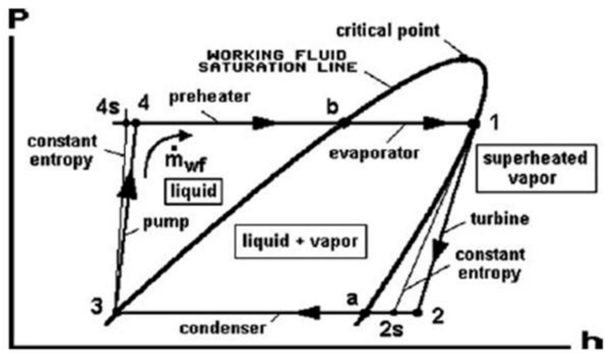
II. METHOD

A. Binary Power Plant as Heat Extraction Method

Binary power plant becoming more common technology used mostly in geothermal application as it used secondary working fluid beside steam as primary working fluid in most geothermal operation. It is the most feasible way that can utilize energy recovered from hot brine that can not be used directly to gear up steam turbine.

The source of heat to be extracted in binary power plant actually in various condition including steam itself (that usually in low pressure and rate that not suitable for commercial power plant) or two phase flow where hot brine and saturated steam flow together in pipeline to heat transfer equipment (Heat Exchanger) to transfer its energy to the working fluid that consider as second working fluid beside high pressure dry steam and commonly known as binary power plant [2].

Binary power plant use secondary fluid that have characteristic like air conditioner working fluid (refrigerant, Organic Hydrocarbon Fluid, Kalina fluid- combination between water and ammonia). It tends to be volatile fluid that easily vaporize and undergo phase change from liquid to superheated fluid.[3]



Working fluid in superheated vapour phase must be in sufficient pressure to rotate the turbine and generator to produce electricity.

Figure 1. P-H Diagram of Binary Cycle

After rotating the turbine the working fluid pressure then flow to the cooler that could be air cooled or water cooled type where it is cooled to change the phase to liquid phase again in the low pressure and temperature condition. A circulation pump then increase the pressure of working fluid to enable it to flow to heat exchanger and repeat again the process.

B. Working Fluid

Many paper already discuss evaluation of ORC- Organic Rankine Cycle as working fluid and the refrigerant type working fluid with the comparison of using certain cycle. For the condition of brine temperature and pressure Pentane was chosen due to having higher molecular weight thus having higher density that more favorable in rotating the turbine. Another important characteristic is the dew point where the tropical climate in Indonesia eventhough in high level altitude with low temperature, the variation of air temperature that required to cool down working fluid to liquid phase on downstream of the turbine is very critical.

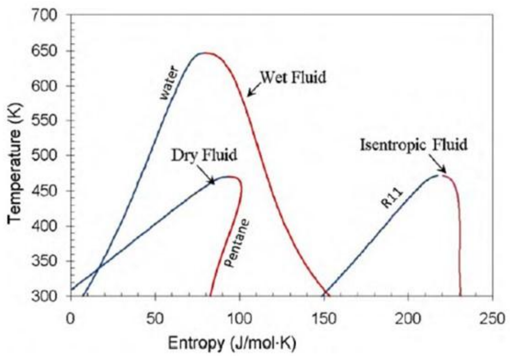


Figure 2. Working Fluid Classification

In downstream of the turbine where the pressure is ~ 16.5 psig, air temperature with the average value of 25^0C could suitably cool down the Pentane to full liquid condition.

Many paper had published research about working fluid such as paper from Zeygamie and Nouraliee [4] that stated that light Hydrocarbon group (Propane, Pentane, Butane) are likely to be choose and the result is not too significant in terms of turbine output. The most predominant factor is air temperature that used to condense the working fluid. Inlet Turbine could be set as high as possible based on temperature of hot brine that vaporize working fluid but the condition of outlet turbine depends on cooling to its dew point of working fluid that can only reach by air temperature as low as possible.

The other factor is Power output of working fluid that give greater output if using higher molecular weight substances thus resulting higher density of vapour to turbine. Although more volatile component like Butane could resulting in higher pressure when become superheated after absorb heat from hot brine compare to Pentane, however the material for piping and heat exchanger will be much affected that requires higher specification and also higher price.

C. Model Development for simulation

The application of binary plant configuration that use in heat recovery system are developed based on common literature and common application. Pentane is used as working fluid due to high molecular weight, suitable thermodynamic properties for binary plant cycle application compare to hot brine condition as source of heat to be extracted. [5]

In steady state condition, Pentane as working fluid entering evaporator and become superheated vapor. The hot brine itself is entering the heat exchanger at 500 psig and 170^0C and the outlet condition is 490 Psia and 90 ^{0}C. This outlet condition is set up to avoid scaling in the pipeline and other equipment.

Pentane in vapor condition then flow to separator to maintain the quality of Pentane vapor at 100% vapor while entering the turbine. High pressure Pentane in vapor condition then rotate the turbine and generator shaft to produce electricity.

Pentane working fluid still in vapor phase leaving the Turbine at temperature of 88.13 ^{0}C and 20 PSIA then directed to condenser to become full liquid at temperature of 39.59 ^{0}C and 16.5 Psia as per phase diagram of Pentane. Pentane working fluid in full liquid phase then transferred by pump to the evaporator again to be circulated to Heat Exchanger evaporator at inlet temperature of 40.1 ^{0}C dan 40 Psia.

The process then repeated in a closed circuit that called binary cycle power plant. To increase energy efficiency of the system then recuperator added to transfer heat of Pentane working fluid from turbine outlet that still in vapor phase prior to entering condenser. Heat from Pentane at the outlet of the turbine transferred to Pentane working fluid after circulation pump prior to entering the evaporator.

By using recuperator the heat from the turbine output could be utilized and the benefit is also reducing the number of cooling duty to condenser. Means that the number of air fin fan cooler required could be reduced. Process configuration of main equipment are shown in figure 3.

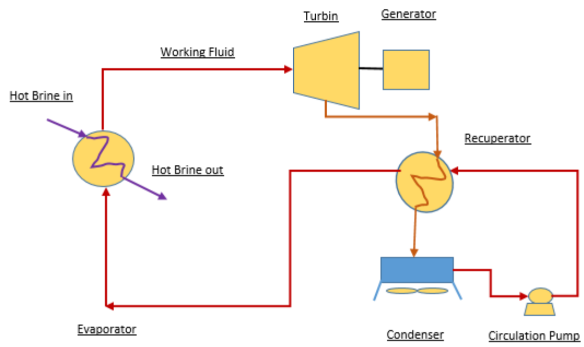


Figure 3. Process Configuration

D. Simulation Input and Optimization

Process simulation is used after process configuration set up for feasible field application. In the process simulation ASME steam fluid package for steam and brine system and Peng Robinson Equation of State was used for working fluid. Hot Brine System and Working Fluid have different basis fluid set up respectively.

As seen in figure 3 the process start with heat recovery from hot brine to Pentane in heat exchanger. This method is refer to Heat Exchanger estimation method, Kern method [6]. Outlet evaporator vapor fraction from evaporator as result of heat transfer from hot brine should be set 1.

Saturated vapor condition of Pentane then optimized by increased the pressure value in small increment until the cycle reach its maximum value which still give convergent result. Condenser pressure and temperature is set as 16.5 Psia and 39.59 ^{0}C respectively. This condenser setting already put into account the average air temperature condition that is 25^0C in average. Condenser parameter setting is important to fulfill requirement of full condensation of working fluid. Working envelope of Pentane in the binary power plant cycle are shown in figure 4.

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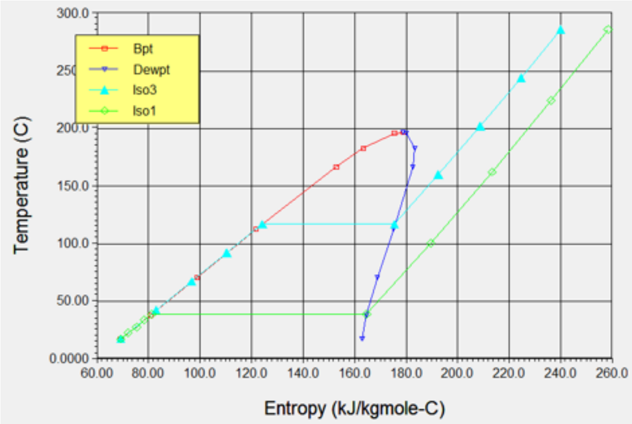

Figure 4. Working envelope of Pentane Working Fluid

Assumption :

1. Process is steady state
2. Pressure drop in piping is neglected
3. Loss in Electrical tie in is neglected

E. Hot Brine Rate Variation

Simulation model and equipment are set up to give optimum result using plateau rate of brine of 953,400 Kg/H. However the dynamic condition of the field might give different result of hot brine available for the heat extraction. Two step of rate below and upper of the average hot brine rate (design rate) will be used and to be discussed furthermore.

F. Economic Evaluation

Method used for economic calculation is based on split on revenue between GOI and operator. Component for GOI are tax, split and local province entitlement. Where income for operator come as portion of NOI- Net Operating Income that regulated in Regulation no 21 year 2014 [7]. NOI are Gross Revenue after deduction of all cost (depreciation and operating cost). Contractor of Geothermal field are entitle of 66% of NOI and GOI- Government of Indonesia is 34%.

Cost estimation was made based on sizing of equipment and some of market study to several binary plant manufacturer.

III. RESULT AND DISCUSSION

Simulation using UNISIM process simulator and optimization had given the following result:

Technical Simulation Output

Table 3. Technical Parameter Output

No	Parameter	Value	Unit
1	Brine Rate	953,400	Kg/h
1	Turbine output	12.8	MW- Gross
2	Pump Load	0.53	MW
3	Air Exchanger Load	0.81	MW
5	Other parasitic load	0.3	MW
6	Net Power Output	11.2	MW
7	System Efficiency	12.08	%

Simulation model using average brine rate in the plateau rate result is tabulated in table 3 where 11.2 MW of net power output after deduction of parasitic load for pump, air cooler and utilities. The total efficiency is about 12.08% which is in the upper range for common binary power plant based on paper by Hyungsul and Sadik. [8]. System efficiency was calculated based on ratio of net work developed to the total energy added by heat transfer [9]

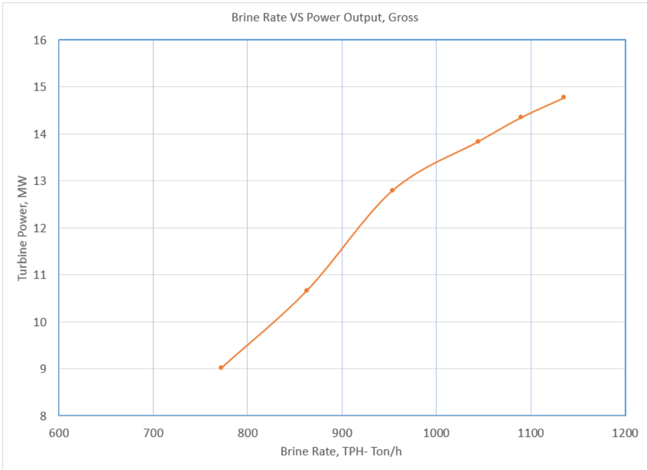

Figure 5. Brine Rate Vs Power Output

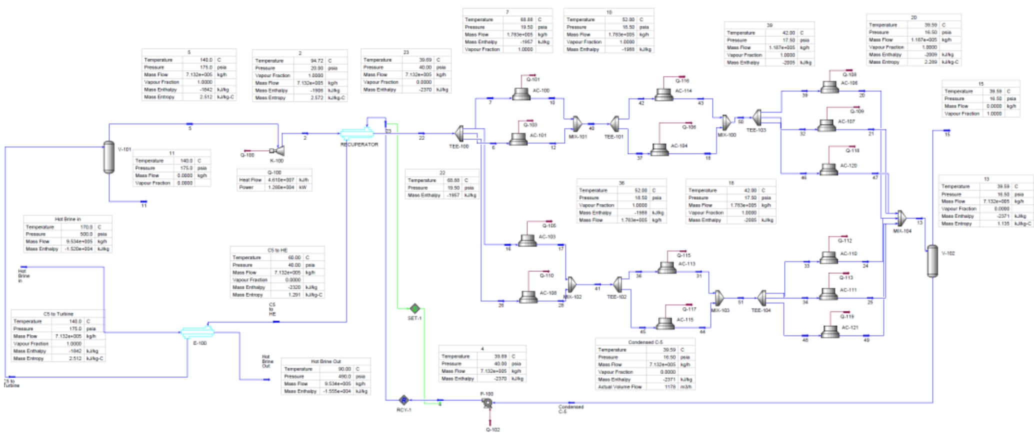

Figure 6. Process Simulation Using UNISIM

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Variation of brine rate as seen in figure 5 was done to evaluate the response of the system when brine rate varied using equipment set up in the plateau rate. Outlet turbine pressure was set equal similar (20 psia). This is more to applicative approach rather than scientific approach where the equipment design are set up according to plateau rate of 953,400 kg/hr of hot brine. It can be seen in that figure that the power output is proportional to brine rate until reach the plateau rate however the power output increase is reduced above that rate because the equipment design in that cycle mainly the air cooler has already reach its maximum capacity hence the Pentane rate also keep steady. The slight increase in power output is due to increase in superheated pressure of the working fluid after evaporator.

Table 4. Technical Parameter Output

No	Brine Rate TPH	Brine Rate KPH	*Power*, MW	*Inlet* Turbine P/T, Psia/^{0}C	Outlet Turbine P/T, Psia/^{0}C	Pentane Rate Kg/h
1	771.8	1,700	9.02	150 / 235.5	20 / 90.7	449000
2	862.6	1,900	10.67	168 / 154.6	20 / 111.5	571400
3	953.4	2,100	12.8	175 / 140	20 / 94.72	713200
4	1,044.2	2,300	13.19	195 / 158	20 / 110.6	713200
5	1,089.6	2,400	13.84	196 / 162	20 / 114.7	713200
6	1,135.0	2,500	14.77	200 / 168.7	20 / 121.2	713200

A. Economical Calculation Result

Economic calculation was made based on Split as mention above (34% share for Geothermal contractor) and capital Investment of 3,700 USD/KWH which refer to range from IRENA (Internal renewable energy Agency) [10] and study conducted by study of Verkis Engineering consultant (2014) for high temperature brine. Operation and Maintenance cost estimated of 120 US/KW/Year at 1.3% escalation per year. Operation and maintenance also include injection of acid or chemicals as scale inhibitor.

Project lifetime is estimated 30 years with 10% depreciation flat for 10 years. The calculation for the project is based on standalone project means that the project economic evaluated only for binary cycle project only not included with the cash flow of other steam turbine units which currently also generate revenue.

Table 5. Summary of Economic at Plateau Rate

No	Parameter	Value	Unit
1	Electricity price	9.6	Cent/kwh
2	*Power* Generated	88.546	MWH/year
3	Load factor	95	%
4	CAPEX	44.8	MM U$
3	OPEX	120	US/kW/Yr
4	NPV (6%)	24.4	MM U$
5	IRR	12.5	%
7	BEP	7.03	Years
8	DPI (@6% discount rate)	1.55	-

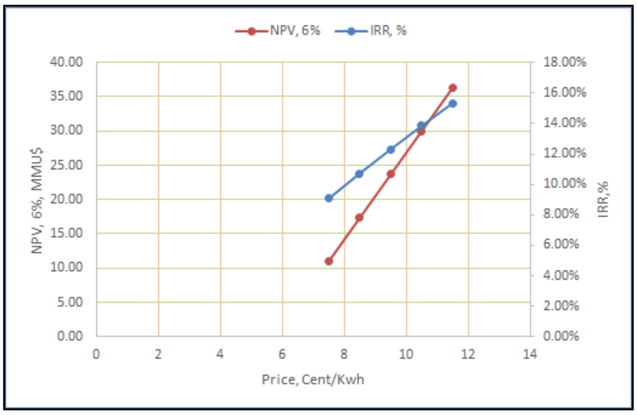

Figure 7. NPV and IRR vs Price

The effect of electric price on NPV and IRR are reflected in figure 7 where 1 cents/kwh increase of IRR and NPV around 1.5% and 6.3 MMU$ respectively.

IV. CONCLUSION

1. Binary power plant application from this "X" field could generate around 11.2 MW from hot brine extraction at its plateau rate.
2. The minimum electricity price to get attractive result from economic aspect is 9.6 cents/kwh.

REFERENCES

[1] Wahjosoedibjo, A. S. and Hasan, M. (2018) 'Indonesia ' s Geothermal Development : Where is it Going?', 43rd Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, (22).

[2] Cengel, Yunus A., Boles, A. M. (2006) Thermodynamics, An Engineering Approach 5th Edition - McGraw-Hill.

[3] R. DiPippo, *Geothermal power plants*, vol. 7. 2012.

[4] M. Zeyghami and J. Nouraliee, "Effect of Different Binary Working Fluids on Performance of Combined Flash Binary Cycle," *World Geotherm. Congr. 2015*, no. April, p. 12, 2015.

[5] B. Radmehr, "Preliminary Design of a Proposed Geothermal Power Plant in Nw-Sabalan Area ," 2005.

[6] Donald Q. Kern, "process heat transfer" New York, N.Y. April , 1950.

[7] DJPK Kementerian Keuangan, "Alokasi Dana Bagi Hasil Sumber Daya Alam," *Https://Www.Kemenkeu.Go.Id/Sites/Default/Files/Dbh%20Sda.Pdf*, 2017.

[8] H. Moon and S. J. Zarrouk, "EFFICIENCY OF GEOTHERMAL POWER PLANTS : A WORLDWIDE REVIEW," New Zealand Geothermal Workshop 2012 Proceedings. November 2012.

[9] B. Adrian, T. George, and M. Michael, "Thermal design & optimization," *New York John Wiley Son, Inc*, 1996.

[10] I. Renewable and E. Agency, "GEOTHERMAL POWER," no. September, 2017.