INSTITUT TEKNOLOGI BANDUNG (ITB) CONTRIBUTION IN RESEARCH OF GEOTHERMAL POWER PLANTS SYSTEM OPTIMIZATION IN INDONESIA

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ABSTRACT

This paper summarizes the research projects on geothermal power plant (GPP) that have been performed by Institut Teknologi Bandung (ITB) students at the undergraduate and postgraduate level. The researches were derived from the geothermal engineering master program, mechanical engineering program, petroleum engineering program, and electrical engineering program. Over 24 years, from 1992 to 2016, 32 researches about system optimization were conducted on several GPPs in Indonesia. The optimization has been done in several GPPs systems such as dry steam, single flash, double flash and binary cycle. The objective of this paper is to produce a research data set by identifying the previous related works. It can be used as a basis to guide future researches to carry out more applicable research to geothermal industries in Indonesia.

1. INTRODUCTION

1.1 Current Status of GPP in Indonesia

Indonesia has enormous potential for geothermal energy, as the country lies along the Ring of Fire where many of volcanoes are located. There are 330 geothermal areas that have been identified in Indonesia (EBTKE, 2016). Most of geothermal systems in Indonesia have high temperatures, many above 225°C. Despite the huge potential, development and utilization of geothermal energy has not been as rapid as expected, with only 1698.5 MWe total capacity installed in 13 geothermal field in Indonesia (a breakdown is shown in Table 1 and Figure 1). Those geothermal fields are operated by several geothermal developers, such as Indonesia Power (IP), Star Energy Ltd. (SE), Pertamina Geothermal Energy (PGE), Geo Dipa Energi (GDE), Perusahaan Listrik Negara (PLN) and Sarulla Operation Ltd (SOL).

For a geothermal project, the power plant must be designed to perform satisfactorily for at least 25-30 years to be deemed economically viable (DiPippo, 2012). Three of 35 (thirty five) units already operated over 30 years, and 40% of the total installed units have been operating for more than half of their expected lifetime. Most of the power plant systems use a single flash system, three of the power plant use a back pressure system and only one of the power plants uses a combined cycle. The operators of the power plants also varies between the government and private sector.

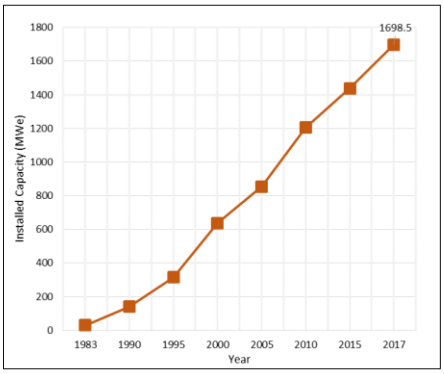

Figure 1: Electricity generated by GPP in Indonesia.

Table 1: Developed Geothermal power plant units in Indonesia as of 2017

Total unit	Field		COD	Installed Capacity (MWe)	Power Generating System	GPP Operator
1	Kamojang	Unit 1	1983	30	Dry Steam	IP
2	Kamojang	Unit 2	1987	55	Dry Steam	IP
3	Kamojang	Unit 3	1987	55	Dry Steam	IP
4	Salak Awibengkok	Unit 1	1994	60	Single Flash	IP
5	Salak Awibengkok	Unit 2	1994	60	Single Flash	IP
6	Darajat	Unit 1	1994	55	Dry Steam	IP
7	Salak Awibengkok	Unit 3	1997	60	Single Flash	IP
8	Salak Awibengkok	Unit 4	1997	60	Single Flash	SE
9	Wayang Windu	Unit 1	2000	110	Single Flash	SE
10	Darajat	Unit 2	2000	93	Dry Steam	SE
11	Lahendong	Unit 1	2001	20	Single Flash	PGE
12	Salak Awibengkok	Unit 5	2002	68.5	Single Flash	SE
13	Salak Awibengkok	Unit 6	2002	68.5	Single Flash	SE
14	Dieng	Unit 1	2002	60	Single Flash	GDE
15	Lahendong	Unit 2	2007	20	Single Flash	PGE
16	Darajat	Unit 3	2007	122	Dry Steam	SE
17	Sibayak	Unit 1	2007	12	Single Flash	PGE
18	Kamojang	Unit 4	2008	60	Dry Steam	PGE
19	Wayang Windu	Unit 2	2009	117	Single Flash	SE
20	Lahendong	Unit 3	2009	20	Single Flash	PGE
21	Lahendong	Unit 4	2011	20	Single Flash	PGE
22	Mataloko	Unit 1	2011	2.5	Back Pressure	PLN
23	Ulumbu	Unit 1	2012	2.5	Single Flash	PLN
24	Ulumbu	Unit 2	2012	2.5	Single Flash	PLN
25	Ulubelu	Unit 1	2012	55	Single Flash	PGE
26	Ulubelu	Unit 2	2012	55	Single Flash	PGE
27	Patuha	Unit 1	2014	55	Single Flash	GDE
28	Ulumbu	Unit 1	2014	2.5	Back Pressure	PLN
29	Ulumbu	Unit 2	2014	2.5	Back Pressure	PLN
30	Kamojang	Unit 5	2015	35	Single Flash	PGE
31	Lahendong	Unit 5	2016	20	Single Flash	PGE
32	Lahendong	Unit 6	2016	20	Single Flash	PGE
33	Ulubelu	Unit 3	2016	55	Single Flash	PGE
34	Sarulla	Unit 1	2017	110	Combined	SOL
35	Ulubelu	Unit 4	2017	55	Single Flash	PGE

1.2 Brief about GPP Research in ITB

Several challenges including a lack of research and expertise in the geothermal business may be the reason why geothermal development has slow progress in Indonesia.

Academic institution including Institut Teknologi Bandung (ITB), as one of the stakeholders in the geothermal industry, may give a positive contribution in terms of research and expert advice to geothermal industries. Together with other stakeholders, research and development at ITB will assist the gaining of the mutual objective, which is the development of geothermal utilization so that Indonesia will reach energy autonomy.

ITB has a number of areas of expertise, with some groups focusing on geothermal research, especially on geothermal power plants. The group of experts who are active in geothermal engineering research include the geothermal engineering master program, mechanical engineering (both bachelor and master program), electrical engineering master program and petroleum engineering bachelor program.

1.3 Objectives

The objective of this paper is to produce a research data set by identifying the previous related works. It can be used as a basis to guide future researches to carry out more applicable research to geothermal industries. It is related to ITB's mission to innovate and apply science and technology for better Indonesia and the world.

1.4 Importance of the Paper

This paper is important because it continues support for research in geothermal power plants and because it encourage geothermal development and helps to create more efficient, reliable, and economic technology development in the geothermal industry.

2. FINDINGS OF GPP RESEARCH IN ITB

From the various groups with expertise related to geothermal power plants, 32 research projects in the form of bachelor and master theses have been identified. Each of these research projects can be divided into 3 categories by topic, namely: optimization of power plant systems, enhancement of component performance and maintenance. The general topic which has been discussed in this paper is about optimization of power plant system. The amount of the research about this topic is given in Figure 2.

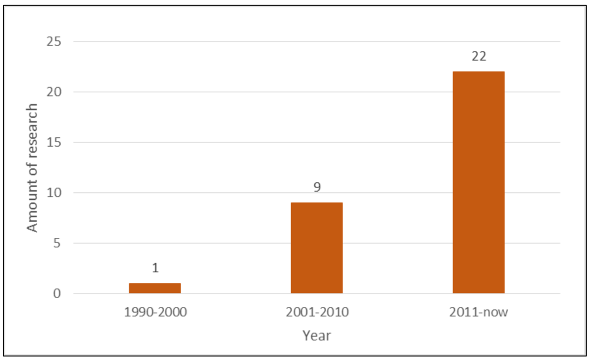

Figure 2: Total amount of research at ITB.

2.1 Optimization of Power Plant System

Based on Law No. 32/2009 about Environmental Protection and Management, Indonesia's Government encourage all geothermal companies to conduct audit of energy activities periodically. Furthermore, Ministry of Environment Decree No. 5/2011 obligates the owners to implement energy audit as a part of Program for Pollution Control, Evaluation, and Rating (PROPER). The aim of PROPER is to manage the environmental sustainability by evaluating the energy usage efficiency for every geothermal power plant (GPPs) components. The evaluation result is reported periodically every 3 years. Therefore, it is important to have a discussion about the optimization of GPPs systems in order to find the alternative solutions to minimize the energy loss in GPPs main components, so that the optimal operating conditions can be achieved.

A number of studies to optimize GPPs generation system were also conducted by the students. The assessments of thermodynamics of the system and main component performance were performed in several Indonesian GPPs. Most of research topics about plant optimization in ITB discuss about dry steam, single flash-steam and binary cycle systems, which will be discussed below.

2.1.1 Dry Steam and Single Flash System

Dry steam and single flash system are the most common type of GPPs configuration in the industry. The difference between dry steam and single flash system component lies on the separation equipment due to the phase of geothermal fluids. Dry steam system does not require separator to separate geothermal fluid from production well, while single flash system uses separator.

The main components of dry steam and single flash system are turbine generator system, condenser, gas removal system (GRS), hot well pump (HWP), circulating water pump (CWP) and cooling tower (CT). Each component has to be evaluated periodically to maintain the optimum performance.

The energy audit on several GPPs have conducted in ITB, started in 2013 by Nugraha then followed by Ahmad and Sakti in 2015. Since there is no Indonesian National Standard (abbreviated SNI) about energy audit, Nugraha used the American Society of Mechanical Engineers (ASME) international standards as a guideline for designing and testing mechanical equipment.

To facilitate the auditor in selecting the proper procedures for specific equipment, ASME generates more than 600 code names for different type of mechanic and electric components. For example, ASME provides code PTC 6 for steam turbine. It focuses on steam turbine audit and evaluation procedure. The evaluation result shows the steam turbine performance based on its heat and steam rate.

In 2015, Ahmad and Sakti also have conducted an energy audit of GPPs system. Contrast to Nugraha's research, they only conduct energy audit based on thermodynamic principles without using international standards. Ahmad has audited vapor-dominated GPPs system, whereas Sakti has audited liquid-dominated GPPs system. Each audit result will be reported to the company in order to minimize the energy losses so that preventive actions can be taken as soon as possible. This audit not only focuses on evaluating and maintaining the component performance, but also gives alternative solution to manage energy waste by converting it into another opportunity.

Susanto in 2005 remodeled the dry steam GPPs system using Cycle Tempo® 5.0 and VBA Excel Macros software. The optimization analysis was performed by varying the operation parameters on Turbine Inlet Pressure (TIP), condenser pressure and mass flow rate. The optimal condition was achieved by increasing TIP, decreasing condenser pressure and increasing steam flow rate. The simulation result shows that the thermal efficiency, exergy efficiency and net output power (61.53 MW from 60 MW) increases.

Ambarita in 2012 done research on system optimization by using empirical approach. The power can be increased by increasing the steam flow rate to the turbine. However, the required steam flow rate was limited by the capacity of cooling water pump.

A similar study was conducted by Iqbal in 2010. He did the optimization design by utilizing excess steam (10% of the total steam flow rate) in accordance with SSC (Steam Sales Contract) between PGE and IP for power generation. Iqbal designed a new GPP with a dry steam system to generate an optimum net power output of 15.19 MW by varying the gas extraction system.

The research of optimization was also conducted in the other steam dominated field by Sinaga in 2013. The generating capacity at that time was 121 MW at 110% load. The largest utility power was on hot well pump and cooling tower fan. The optimization of both utilities were applied by using Variable Frequency Drive (VFD) application. Engineering Equation Solver (EES) software was used to perform modeling by varying the load at 110%, 100%, and partial load. The operating system was optimized at 110%.

Wirawan in 2010 reviewed thermodynamics of the double flash system in Wayang Windu GPP Unit 1. Analysis performed on two types of double flash system: double flash single turbine and double flash dual turbines. The additional power generated from the first system was 3.49 MWe and from the second system was 2.07 MWe. The low pressure separator (Weber separator) has been designed in this research.

Adipradana in 2015 did a study on optimization using exergy profile to find component that has deteriorated or has performance trouble. The component studied in this study are steam receiving header, demister, turbine, condenser, cooling tower, intercondenser, aftercondenser and intercooler. Based on analysis in this research, the power plant problem was directly affected by condenser cooling water temperature. Cooling tower modification was applied by decreasing condensate flow rate and increasing fan blade pitch. It reduces the steam supply requirement by more than 11 t/h for each unit.

Suryadi in 2015 investigated the effect of decreased TIP to system while maintaining the same electricity output. It leads to increase of steam mass flow rate and velocity all over the system. In order to accommodate flow increase, the component that needs to be replaced are the pipeline between control valve prior to the scrubber and the turbine inlet.

Nanang in 2015 made a study on the selection of GWGU development. Geothermal Wellhead Generating Unit (GWGU) is a system developed for optimizing idle wells during large-scale generator construction or relatively low pressure wells that cannot be used in the main GPP system. Considering potential scaling, the separator pressure in Field 1 is 3 bar and Field 2 is 4.25 bar. Based on technical analysis, economic analysis and field conditions, the GWGU backpressure turbine type is more appropriate for use Field 1 and mini condensing steam turbine for Field 2.

2.1.2 Binary Power Plant System

Binary cycle is an alternative GPPs configuration for low-medium enthalpy prospects. This system uses secondary working fluid to transfer heat from geothermal brine which is then directed to a turbine to generate electricity. To accommodate heat transfer from brine to binary system, the working fluids must have lower boiling point than geothermal brine.

The first research regarding GPPs optimization in general and specifically binary cycle at ITB was done by Pakaja (1992). He discussed the optimum binary cycle design at the medium geothermal resource. This research contains the basic concept of binary cycle system and its component.

The binary cycle system is a popular research topic due to the lack of development of the abundant low-medium enthalpy prospects in Indonesia. Binary cycle is also an attractive option to utilize waste heat from brine. Some researches have done heat and mass analysis of binary cycle in regards to the respective field properties as input. The proposed binary cycle system configuration will be iteratively calculated for multiple working fluids and then optimized until the best result was obtained. Table 2 show the results of some of relevant researches done at ITB.

Table 2: List of ORC Researches

Year	Working Fluid	Thermal Efficiency	System	Author
2010	Isopentane	12.29 %	Simple ORC	Gunawan, C.
2010	N-Pentane	11.99 %	Simple ORC	Gozaly, J.
2012	Isopentane	11.65%	Simple ORC	Widarto, W.A.
2013	R134a	23.33%	Simple ORC	Nugratama, A.
2013	Isopentane	12.66%	Simple ORC	Berutu, S.
2014	Isopentane	15.01%	Simple ORC	Kurniawan, D.
2014	Pentane	16.44%	Simple ORC	Prasojo , R.I.
2016	R152a	16.09%	ORC with Recuperator	Yusuf, D. E.
2016	Pentane	15.78%	Simple ORC	Mahagun, Y.

Gunawan (2010) and Gozaly (2010) have studied binary cycle performance. They also determine the specification of binary cycle main component, as shown in Table 3.

Table 3: Specification of binary cycle main component

Component	Type
Evaporator	AKT Shell and Tube
Shell Material	Carbon Steel ASTM A516-60
Tube Material	Duplex Stainless Steel SAF 2205/ASTM 789
Condenser	Forced draft with 6 fans

Gunawan analysis shows that Isopentane can generate highest net power. However, Isopentane needs higher initial cost compared to n-pentane. His calculation shows that isopentane configuration needs 2 years and 5 months to recoup the gap and become more profitable compared to n-pentane, the second best option.

Berutu (2013) has also done economic assessment to ORC system design based on the brine output of water dominated field. He suggest that the overall investment value for ORC system development is US$ 3,502. The minimum electricity price he offered is 12.275 cent with IRR value of 16%. It will take around 9 years to return the value of investment.

Other than these system assessment, there have been researches that investigate modification of ORC system that will be outlined below.

Ghafery (2010) investigated the replacement of condenser of a single flash system in Dry steam GPP system to multiple configurations: an ORC system, another flash system so that it become double flash system, and additional separator that supply steam turbine and ORC system. It's found that replacing condenser to ORC system in the case of this field makes the net output lower, while the other modification options only give relative increase of ~1%.

Sinembadan (2010) has investigated the effect of coupling the separated brine to a two-level ORC system as depicted in Figure 3. In this ORC system, separated brine transfers heat to two vaporizers consecutively. After that the brine flow is split and used to transfer heat to each preheater of both ORC systems.

Two-level ORC system makes it possible to use two separate working fluids for every stage. In a case study of water dominated field, the usage of Butane on first-level ORC and Isobutane on second-level ORC was proposed. This configuration has a net thermodynamics efficiency of 14.6%.

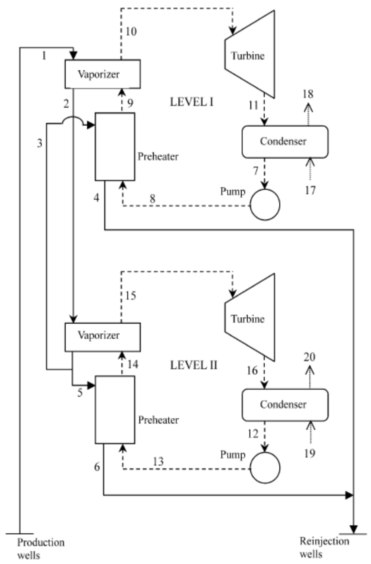

Figure 3: Two-level ORC system (Sinembadan, 2010)

Fathoni (2013) compared Single Flash system with ORC attached at separated brine output (combined cycle) with a system called Integrated Flash-Binary Brine-Steam Power ORC Geothermal Power Plant (hybrid cycle). In this proposed system, the exhaust steam from a flash cycle and separated brine are used separately to heat the working fluid. Both of them are mixed and then go to the ORC cycle's preheater. Schematic of this system is depicted in Figure 4.

He found that the combined cycle has superior thermodynamics performance compared to hybrid system. However, the hybrid system has the benefit of diluting the brine and reducing the risk of silica scaling in the plant that will improve the maintainability of the system.

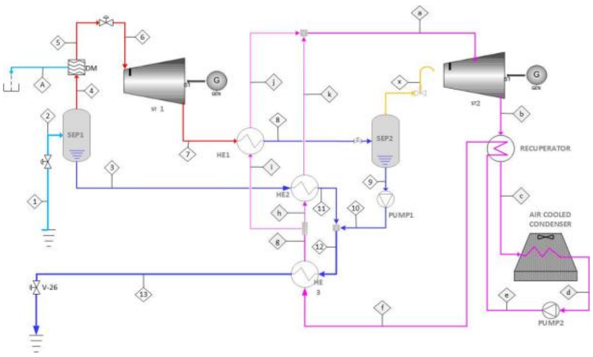

Figure 4: Integrated Flash-Binary Brine-Steam Power ORC Geothermal Power Plant (Irianto, 2016)

Irianto (2015) expanded Fathoni's research by studying NCG effect to single flash, combined cycle, and aforementioned hybrid cycle. Figure 5 shows the effect of varying NCG content on the net output of the compared systems. The result shows that hybrid cycle net power output is not significantly impaired by the existence of NCG, unlike the other two systems compared. The hybrid cycle is viable for use when NCG content in steam exceeds 8%w.t.

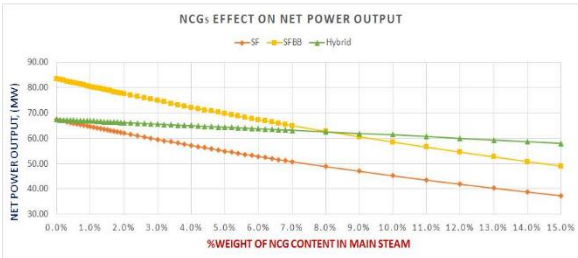

Figure 5: NCG effect on the compared Geothermal Power Plants (Irianto, 2016)

Oentara (2015) did research on the performance of a new bottoming binary cycle system design by GFZ (Geo Forschungs Zentrum, German Research Centre for Geoscience). This design used hot water as an intermediary between separated brine and binary cycle system with a recuperator which describe in Figure 6. The intermediary cycle will reduce the efficiency of the system. However, this configuration has plenty benefits. The intermediate cycle has a pump that can control water flow rate. This will help maintaining the amount of heat received to the ORC unit, thus increasing system reliability. This configuration will also reduce the operational cost significantly due to easier maintenance and lower working fluid replacement needs.

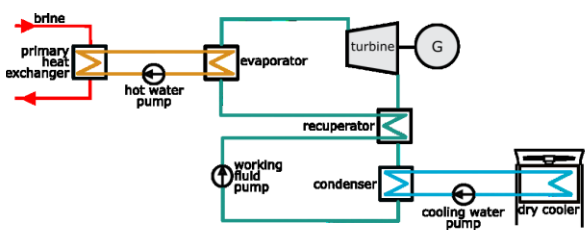

Figure 6: ORC system with intermediary cycle (Oentara, 2015)

Baragbah (2015) investigated the performance of multiple ORC modifications with regards to the Jailolo Geothermal field. One of the modification offered is the usage of open feed-water as depicted in Figure 7. This configuration needs more brine to run, but the output brine temperature will be increased significantly. The overall thermal efficiency will also increase at the cost of reduced exergy efficiency.

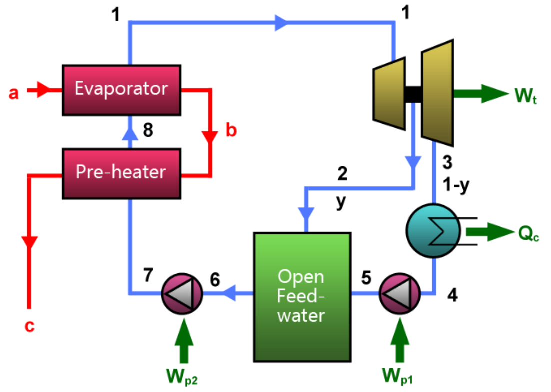

Figure 7: ORC system with open feed water (Baragbah, 2015)

3. DISCUSSION AND SUMMARY

ITB research efforts have concentrated on optimization of power plant systems based on current condition of GPPs in Indonesia. Some optimization performed either by modifying the thermodynamics preference of system or sizing the dimension of component to increase the efficiency. The existing dry steam and single flash system from several GPPs have been used to simulate the model. Certain binary conversion cycles were also designed to increase the power output (hybrid or combined cycle) or to optimize the utilization of low and medium enthalpy.

By reviewing ITB researches about GPP, can be concluded some researches are just repetition from previous researches especially because the limitation of use and publicity industry data is one of the causes of the lack of research in ITB. The ITB research team needs a control system that leads researchers to get beneficial topics for scientific development and also may be applied in the industry. In addition, the transfer of knowledge is needed more so that researcher who enter the thesis program have better preparation and understanding in certain desired topics.

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