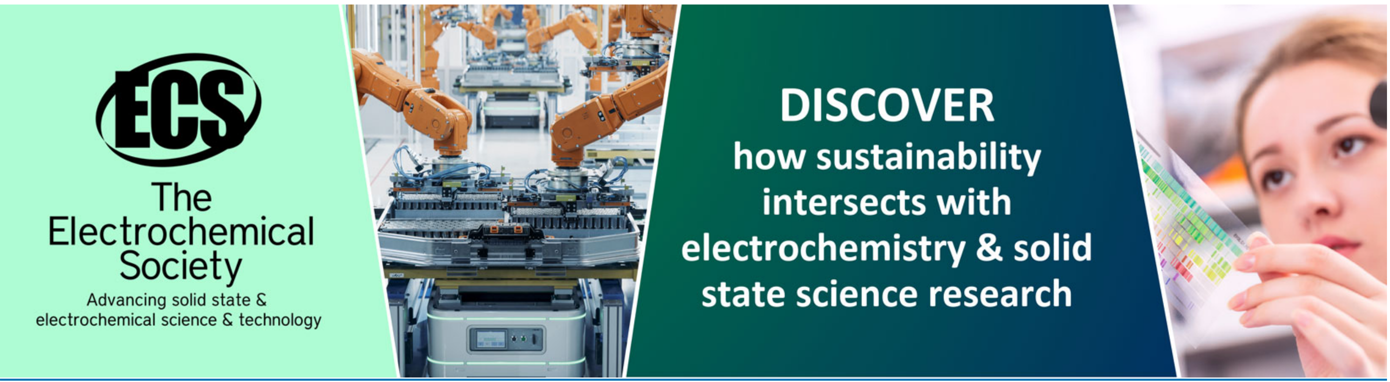
IOP Conference Series: Earth and Environmental Science

Pre-feasibility Study of Condensing Wellhead Generating Unit Utilization in Partially Vapor Dominated System

To cite this article: M A Dahlan *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **417** 012021



IOP Conf. Series: Earth and Environmental Science **417** (2020) 012021 doi:10.1088/1755-1315/417/1/012021

Pre-feasibility Study of Condensing Wellhead Generating Unit Utilization in Partially Vapor Dominated System

M A Dahlan[1], H B Pratama[2], N M Saptadji[2]

[1]Petroleum Engineering Study Program, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
[2]Geothermal Engineering Study Program, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
Jl. Ganesha No. 10, Bandung, West Java, Indonesia. 40132

Email: alwydahlan.ad@gmail.com

Abstract. The development of geothermal fields needs 5-6 years from the first well drilled until the operation of the central power plant. Between the gap years, the wells will be shut in and will be re-opened when the power plant is ready. However, there is an alternative to utilize the wells with Wellhead Generating Unit (WGU), the small power plant which can generate the electricity as soon as the drilled productive wells completed. Then, the objective of this study is to decide the preferable scheme for the installed capacity of WGU with economic consideration. Correspondingly, this study uses two full factorial experimental design with Monte Carlo simulation to calculate and design the condensing turbine. Steam fraction, mass flow rate, turbine inlet pressure, and turbine exhaust pressure are the parameters to be analyzed in the Monte Carlo Simulation. The economic feasibility of the project is based on capital expenditure, decline curve analysis, and electricity price. The result of probability, P10, P50, and P90 of gross power output and Specific Steam Consumption (SSC) are 6.1, 7.9, 9.9 MWe and 1.85, 1.89, 1.93 kg/s/MWe respectively. Based on the economic evaluation, the P10, P50, and P90 of Internal Rate of Return (IRR) and Net Present Value (NPV) are 12%, 16%, 21% and 1.1 MUSD, 3.6 MUSD, 6.0 MUSD respectively over 30 years of WGU lifetime. This paper is the first study for designing the WGU combined with an economic study based on the technical evaluation to propose the best option to develop the field.

1. Introduction

In the early phase of development, some exploration wells have a chance to become productive wells after conducted by several well testing. However, to complete the construction of the central power plant need more extended time from the first accomplished exploration well. The wells will be shut in during the construction, or in another word, it will be disposed of wasteful steam. Hence, the steam will be utilized immediately after completing the drilled wells to reduce those losses with Wellhead Generating Unit (WGU). WGU will turn the steam into electricity.

In WGU, steam is extracted from the well and converted to electricity at the wellhead [1]. Different from the conventional power plant, the construction of WGU is placed on a portable unit. Because of this, it is easy to move to another place. The other characteristics of WGU are the re-usability, modest capital investment, and rapid power production capability [2]. The most promising applications of WGU include on-site industrial use, electricity supply in remote areas, as a tool for developing geothermal fields, and peak units for larger utilities [2]. For this study, WGU will be applied to a specific geothermal system; it is the partially vapor dominated system.

Partially vapor-dominated system is represented by the reservoir system of Karaha Talaga Bodas Field. Calculation and design of WGU will be based on data in this field. In the Karaha Talaga Bodas field, the current capacity of the installed power plant is 30 MWe and commercially operated (Commercial on Date) on 6th April 2018.

Determination of WGU capacity needs to be done before it can be applied in the field. The proper installed capacity of WGU can be approached by experimental design. In this study, the installed capacity of WGU will be calculated by full factorial experimental design with Monte Carlo simulation to get the probabilistic result. Full factorial in Experimental Design (ED) is a systematic way of involving several factors where it is necessary to investigate the combined effects of the factors on a response variable [3].

The study of probabilistic approach for calculation and design of WGU was done by [4]. In the previous study, the calculation and design of WGU were in the vapor-dominated system. The type of WGU used was a backpressure turbine and there was no economic feasibility evaluation. However, this study used a condensing turbine. Then, the economic evaluation was used to determine the feasibility of WGU for the geothermal system. The ED was also used to find the location of borehole optimally in the geothermal field [5]. The application of systematic ED was used to approach a geothermal reservoir simulation model to generate probabilistic resource assessment results [6]. The experimental design was also applied in geothermal resource assessment in Ciwidey-Patuha, West Java, Indonesia [7].

The objectives of this study are to determine technical empiric equations of gross power output and Specific Steam Consumption for the condensing turbine represented by the probabilistic result, P10, P50, and P90. Then, calculate the economic consideration of condensing turbine based on the technical evaluation, especially for this geothermal system.

2. Wellhead Generating Units

WGU is the small power plant compared to the conventional power plant and can generate electricity from 1 to 15 MW, with the largest offered being 25 MW [8]. As the name suggests, WGU placed on the same wellpad as the location of production wells. Therefore, WGU uses short pipelines to transport the production fluids from one or a group of wells to the generating unit.

There are several types of commercial WGU, depending on the characteristics of the geothermal resource being developed and the kind of conversion cycle being used. The major types of WGU are backpressure wellhead units, condensing wellhead units, and binary wellhead units. For this study, only one types of WGU are used for designing. It is a condensing turbine.

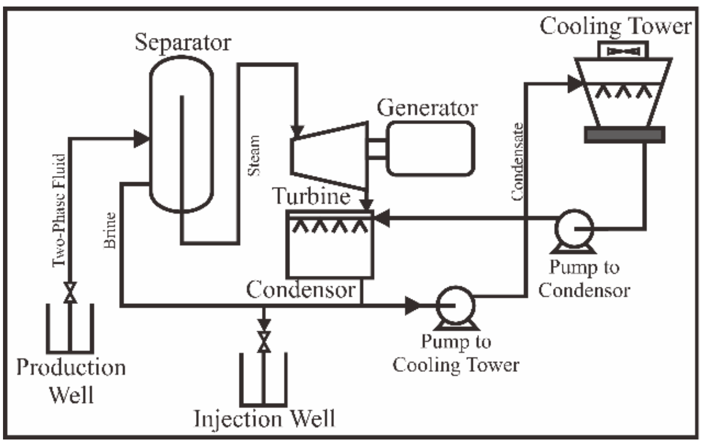


Figure 1. Schematic of condensing turbine (modified from [2]).

The schematic of the condensing turbine is shown in Figure 1. Condensing turbine with the type of single flash system is used for this study. Two-phase fluid from the wells flows into the separator to separate the steam and brine. The steam from the separator will going through the turbine to generate the electricity. Then, brine or condensate will be injected back into the reservoir.

Table 1 shows some examples of case studies of WGU application worldwide. The table also shows the different capacities, types, and objective of WGU for geothermal resources development. WGU is not a new technology because since 1966 it has been used in Matsukawa, Japan with backpressure turbine for well testing [9]. In Kamojang, Indonesia, the utilization of WGU began in 1978 with backpressure turbine [10]. While, the utilization of condensing turbine is in 2011 and 2012 for pilot projects of geothermal resources development in Olkaria and Eburru, Kenya [1].

Table 1. Case Studies of WGU application worldwide.

Year	Field	Country	Capacity	Type of WGU	Objectives
1966	Matsukawa	Japan	1 × 0.45 MW	Backpressure Turbine	18 months well testing [9]
1969	Namafjall	Iceland	1 × 3 MW	Backpressure Turbine	First project utilization of geothermal resources [9]
1978	Kamojang	Indonesia	1 × 0.25 MW	Backpressure Turbine	First project utilization of geothermal resources [10]
1982	Los Azufres	Mexico	5 × 5 MW	Backpressure Turbine	Test the new field [11]
1995	Miravalles	Costa Rica	1 × 5 MW	Backpressure Turbine	Provide electricity during drilling phase and well test [12]
2011	Olkaria	Kenya	1 × 5 MW	Condensing Turbine	Accelerate the utilization of geothermal resource [1]
2012	Eburru	Kenya	1 × 2.5 MW	Condensing Turbine	Pilot project of WGU with shut in wells since 1990 [1]

The most characteristic feature of a wellhead generating facility is its modular construction. The turbine-generator modules are assembled at the factory on one or more skids [8]. Therefore, they will easily and securely be transported and used as a unit. And because of the modular construction, the space requirements of a wellhead power plant could be a minimum of 60 m by 30 m with the typical size of wellpads measure approximately 100 by 100 m [13].

Other advantages of WGU that make it more attractive in the geothermal industry are as follow. Because of their size and packaging, WGU can be operated faster, which is only about 6 months while conventional plants need 2-3 years. Hence, the use of WGU can allow the investors to earn their revenue in a shorter period. WGU can also be used in areas with complex topographic conditions or remote areas. Furthermore, there are some disadvantages from using WGU; those are the capital cost and operating cost are relatively high per MW due to small installed capacity. There are new problems in operation and maintenance if there are many WGU spread in one field, also new problems on handling brine or condensate disposal if the wells produce two-phase fluid [14].

3. Methodology

The methodology used for this study as presented in Figure 2. Start from determining the gross power output and specific steam consumption (SSC) of WGU until the economic feasibility calculation.

The objectives of this study are fulfilled by the calculation of gross power output and SSC to determine the size of the installed capacity of WGU. All parameters which affect the performance of WGU will be chosen. For this study, full factorial experimental design with Monte Carlo simulation is used to calculate and design WGU. Significant parameters are analyzed by the Pareto Chart. Then, the first-order polynomial application will be selected as the proxy model. For economic consideration, the feasibility of WGU will be calculated for this geothermal system.

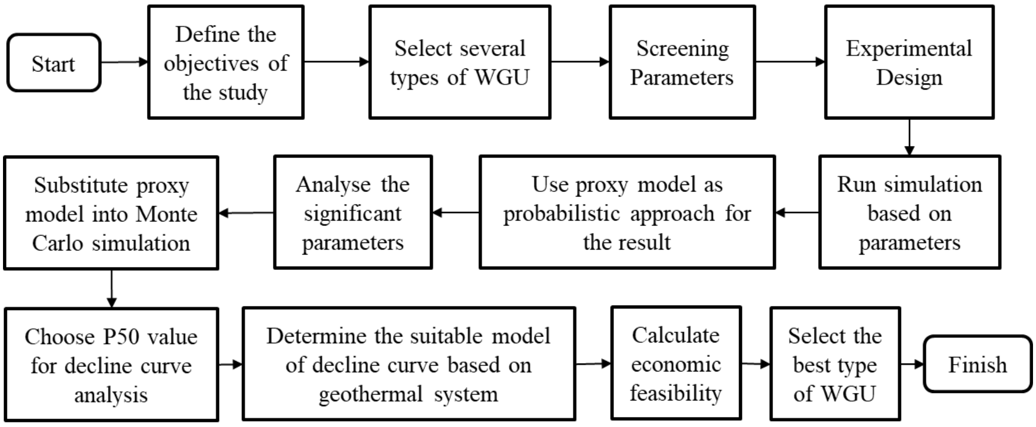


Figure 2. Experimental design and economic feasibility workflow of WGU.

3.1. Technical Section

Well test data that has been performed in each well with condition of shut-in wells and they are tabulated in Table 2 [15]. Well test data of KRH 4-1 and KRH 5-1 are good for input data. For KRH 2-1 RD and KRH 3-1ST had oscillated fluid flow during the test. K-33, T-2, and T-8 are slim-hole wells with shallow depth and fewer total mass rate. TLG 1-1ST2 and TLG 2-1 produced vapor fluid with high contained acid. Then, TLG 3-1 produced two-phase fluid, but it was not used for the input data because the concerned area of this study was only on the north area of Karaha Talaga Bodas.

Table 2. Well test data of Karaha Talaga Bodas.

Well	Well Type	Wellhead Pressure (bara)	Total Mass Rate (kg/s)	Enthalpy (kJ/kg)
KRH 1-1ST	Standard	The fluid had not flowed sustainably		
KRH 2-1RD	Standard	4	32 – 101	1163
KRH 3-1ST	Standard	5	15 – 38	1163 - 1628
KRH 4-1	Standard	8	35	2210
KRH 4-2RD	Standard	Flow test was not conducted in this well		
KRH 5-1	Standard	8	25	1396
K-33	Slim Hole	10	2	2035
TLG 1-1ST2	Standard	10	8	2559
TLG 2-1	Standard	8	5	2675
TLG 3-1	Standard	8	16	2559
T-2	Slim Hole	16	3	2675
T8	Slim Hole	8	3	2652

Gross power output generated by turbine-generator can be calculated by Equation (1) [14] [16] below:

$$W_e = \frac{x \times \dot{m} \times \eta_t \times (h_{TIP} - h_{cond.})}{1000} \quad (1)$$

where W_e is the gross power output in MWe, x is the steam fraction in the wellhead, $\dot{m}$ is the total mass flow rate in kg/s, η_t is isentropic turbine efficiency in percentage, h_{TIP} is specific steam enthalpy at turbine inlet pressure in kJ/kg, and $h_{cond.}$ is specific steam enthalpy at condenser in kJ/kg.

SSC determines power plant performance. SSC is the amount of steam in kg/s consumed by power plant to generate 1 MW of electricity. SSC can be calculated by Equation (2) [14] [16] as follows:

$$SSC = \frac{x \times \dot{m}}{W_e} \quad (2)$$

where *SSC* is specific steam consumption in (kg/s)/MWe, x is the steam fraction in the wellhead, $\dot{m}$ is the total mass flow rate in kg/s, and *We* is the gross power output in MWe.

Four significant parameters which affect the calculation of gross power output and SSC are in Table 3. The mass flow rate which flowing to turbine will affect the number of electricity generating capacity. The turbine inlet pressure and condenser pressure will affect the enthalpy of the fluid.

Table 3. Parameters of condensing turbine.

Parameter	Low (-1)	High (+1)	References
Steam Fraction	0.3	0.7	[15]
Mass flow rate (kg/s)	25	35	[15]
Turbine Inlet Pressure (bar abs)	6	6.5	[17]
Turbine Exhaust Pressure (bar abs)	0.08	0.12	[16]

3.2. Experimental Design

Full Factorial experimental design with Monte Carlo simulation is used to calculate and design the condensing turbine. ED is the study of the effect on a response of k factors, each at two levels. These are commonly known as 2^k factorial experiments where k is the number of parameters [18]. The parameters are often denoting the levels as "high" and "low" in dimensionless variables, i.e., -1 for low and +1 for high. Experimental design will be applied in WGU to calculate the gross power output and SSC. A two-level, four-parameter full factorial design requires 2^4 or 16 simulation runs. This is shown in Table 4. The simulation of ED was using Minitab 18™ software.

Table 4. A two-level, four-parameter full factorial design.

StdOrder	RunOrder	x	$\dot{m}$	TIP	TEP	StdOrder	RunOrder	x	$\dot{m}$	TIP	TEP
7	1	-1	1	1	-1	12	9	1	1	-1	1
2	2	1	-1	-1	-1	8	10	1	1	1	-1
3	3	-1	1	-1	-1	1	11	-1	-1	-1	-1
4	4	1	1	-1	-1	13	12	-1	-1	1	1
6	5	1	-1	1	-1	11	13	-1	1	-1	1
9	6	-1	-1	-1	1	10	14	1	-1	-1	1
15	7	-1	1	1	1	16	15	1	1	1	1
14	8	1	-1	1	1	5	16	-1	-1	1	-1

Probabilistic approach of polynomial response or proxy models is used to define the simulation results and the tested parameters in Table 3. Equation (3) shows a first-order polynomial approximation of the simulations from the design.

$$y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_5 AB + \beta_6 AC + \beta_7 AD + \beta_8 BC + \beta_9 BD + \beta_{10} CD + \beta_{11} ABC + \beta_{12} ABD + \beta_{13} ACD + \beta_{14} BCD + \beta_{15} ABCD \quad (3)$$

where y is simulation results, βs are the regression coefficients, A is the coded variable that represents x, B is the coded variable that represents $\dot{m}$, C is the coded variable that represents *TIP*, and D is the coded variable that represents *TEP*. The regression model can be used to predict the response at any point in the space spanned by the factors in the design [3].

3.3. *Economical Section*

The economic feasibility will be evaluated by using financial model. A financial modeling is concerned with the development of tools investors, governments, etc, in their financial-economic decision making, including the validation of the premises behind these tools and the measurement of the efficacy of these tools [19]. In this study, the financial model is divided into four calculation sheets. They are Investment Cost and Expense, Loan Schedule, Income Tax, and Cash Flow, modified from [20]. Figure 3 depicts the structure and interrelationships between the calculation sheets in the financial model.

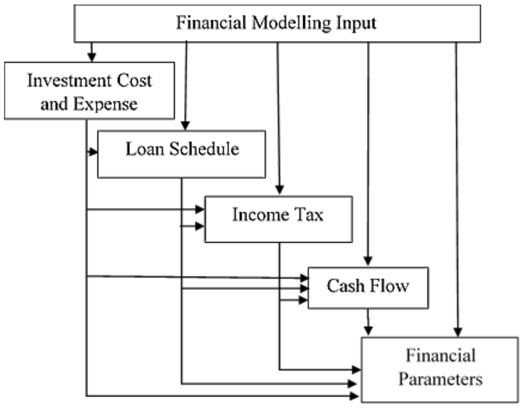


Figure 3. Financial model structure (Modified from [20]).

3.3.1. Technical and Financial Assumptions. The assumptions used in financial modelling are divided into two parts, technical and financial assumptions. Table 5 summarizes the technical assumptions and Table 6 tabulates the financial assumptions. In technical and financial assumptions, there is no allocation for make-up well because this study wanted to know the effect of decline curve on the performance and economics of WGU for a certain period.

Table 5. Technical assumption.

Technical Parameters	Value	Unit	Reference
Wellhead Economic Life	30	Years	[21]
Number of Production Well	1	Well	-
Number of Injection Well	1	Well	-
Capacity Factor	90	%	[21]

Table 6. Financial assumption.

Financial Parameters	Value	Unit	Reference
Depreciation	8	Years	[22]
Depreciation Rate	25	%	[22]
Equity : Loan	30 : 70	%	[23]
Loan Period	20	Years	[24]
Interest	4	%	[24]
Interest During Construction	4	%	[24]
Tax Rate	25	%	[25]
Discount Rate	10	%	[24]

3.3.2. Revenue. The P50 result of gross power output will be the input for declining curve analysis over 30 years. The suitable model of decline curve for this field is harmonic decline curve for the field with vapor dominated. The equation for the harmonic decline model is shown in Equation (4) (Modified from [26]) below:

$$W_e = \frac{W_{ei}}{(1+d_i t)} \tag{4}$$

where, W_e is current gross power output, W_{ei} is initial gross power output (start of production), d_i is initial nominal of decline rate when $t = 0$, t is cumulative time since start of production.

The area under the decline curve of W_e versus time between t_1 and t_2 is a measure of the cumulative gross power output (C_{We}) during a certain period can be expressed as (Modified from [26]):

$$C_{We} = \int_{t_1}^{t_2} W_e \, dt \tag{5}$$

Substituting the gross power output from Equation (4) to Equation (5), and integrating gives:

$$C_{We(t)} = \left(\frac{W_{ei}}{d_i}\right) \ln\left(\frac{W_{ei}}{W_e}\right) \tag{6}$$

where $C_{We(t)}$ is cumulative gross power output at time t, W_{ei} is initial gross power output (start of production), d_i is initial nominal of decline rate when $t = 0$, and W_e is gross power output at time t.

The area below the decline curve multiplied by the electricity price is the total revenue of WGU, which decreased every year. This study did not assume the constant total revenue every year, but it will be following the decline curve analysis and made it more realistic calculation.

3.3.3. Investment Cost and Expense. From this calculation, the equity, loan, and income tax of the project can be estimated. Investment and Expense are built from cost estimation. The estimated cost of a geothermal project can affect the risk and viability of a geothermal project. The cost assumptions for the financial model are summarized in Table 7, where c is the installed capacity of WGU in MW. The economic assessment in this study is assumed by excluding the exploration cost. Exploration cost is the cost spent in the early development stage, such as exploration survey, exploration wells, land access, reservoir modelling study, etc. The exception to exploration cost was made because in this study only wanted to focus on the things that matter in the development of a WGU.

Table 7. Cost assumptions.

Parameters	Price		Unit	References
Production Well Injection Well	4 – 8		MUSD per Well	[27]
Capital Cost of Condensing Turbine	$2500\times e^{-0.003(c-5)}$	(7)	USD per kW	[28]
Transmission	66		USD per kW	[29]
Operation & Maintenance Cost of Condensing Turbine	$2e^{-0.0025(c-5)}$	(8)	US¢ per kWh	[28]

The production well and injection well costs are in the range of four to eight million United States Dollar [27]. The Capital Costs, in USD per kW, are included the separators, turbines, generators, well connections, civil works, and everything that supported the running of the WGU. The Operation & Maintenance Costs, in US¢ per kWh, are calculated based on the gross power output generated by the WGU [28]. Then, the transmission cost, in USD per kW [29].

Depreciation was also considered in this study. Depreciation is accounted for tangible and intangible investments. Tangible investment is an investment spent to buy tangible items Whereas, intangible investment is an investment that is spent to pay for services provided by other parties. Although intangible investment is not visible but has a useful life of more than one year, then it can be categorized as an asset and has a decline in value from time to time called amortization.

For the Loan Schedule, Capital Loan is calculated from total capital multiplied by the percentage of loans from the beginning of the project until before the Commercial Operation Date (COD). Before COD, the loan was added by Interest during Construction (IDC) because there was no revenue. In the Loan schedule, annual repayment is determined since the project has been operating commercially.

For the Income tax, Geothermal developers are required to pay tax from the net income of geothermal utilization to the government. Based on Constitution No. 36/2008, a tax is imposed 25% of net income.

Cash flow is calculated annually from start of the project until 30 years of utilization. Cash flow is built through revenue plus loan capital and reduced by investment costs, interest from loans, income tax, and annual loan repayment. Furthermore, the estimation of cumulative cash flow is needed in determining when the developers will begin to gain a profit.

The financial parameters are used to evaluate the financial feasibility of a geothermal project. In general, the financial parameters that are often used in considering investment decisions are Net Present Value (NPV), Internal Rate Return (IRR), and Pay Out Time (POT). NPV is the sum of a time series of cash flow in present values using a nominated discount rate over the project life. If the value is greater than 0, the investment is more attractive than the discount rate [24]. IRR is the discount rate at which the NPV of all the cash flows from a project equal to zero [24]. POT is the required time to recover all cost in a project. The longer times of POT are usually not desirable for investment position to undertake the project [30].

4. Result and Discussion

4.1. Technical Result and Analysis

The other data to complete the design of vapor dominated system are wellhead pressure with 8 bara [15] and 85% turbine efficiency [16]. After creating 16 models based on parameter condition in Table 4, doing the simulations, and calculating them, the results of condensing turbine are summarized in Table 8. The maximum and minimum result of the gross power output of condensing turbine are 3.8 MWe and 13.6 MWe respectively. Then, the maximum and minimum result of SSC are 1.80 (kg/s)/MWe and 1.98 (kg/s)/MWe respectively.

Table 8. Simulation design run and gross power output and SSC results.

Run-Order	x -	$\dot{m}$ kg/s	TIP bara	TEP bara	We MWe	SSC (kg/s)/MWe
1	-1	1	1	-1	5.8	1.80
2	1	-1	-1	-1	9.5	1.83
3	-1	1	-1	-1	5.7	1.83
4	1	1	-1	-1	13.4	1.83
5	1	-1	1	-1	9.7	1.80
6	-1	-1	-1	1	3.8	1.98
7	-1	1	1	1	5.4	1.94
8	1	-1	1	1	9.0	1.94
9	1	1	-1	1	12.4	1.98
10	1	1	1	-1	13.6	1.80
11	-1	-1	-1	-1	4.1	1.83
12	-1	-1	1	1	3.9	1.94
13	-1	1	-1	1	5.3	1.98
14	1	-1	-1	1	8.8	1.98
15	1	1	1	1	12.6	1.94
16	-1	-1	1	-1	4.2	1.80

The polynomial approximation response was analyzed by Minitab 18™ to generate the gross power output (*We*) and SSC responses of condensing turbine. The first-order polynomial equation of condensing turbine is:

$$We = 7{,}953 + 3{,}181\, x + 1{,}325\, m + 0{,}07700\, TIP - 0{,}3077\, TEP + 0{,}5302\, x*m + 0{,}03080\, x*TIP - 0{,}1231\, x*TEP + 0{,}01283\, m*TIP - 0{,}05128\, m*TEP + 0{,}000682\, TIP*TEP + 0{,}005133\, x*m*TIP - 0{,}02051\, x*m*TEP + 0{,}000273\, x*TIP*TEP + 0{,}000114\, m*TIP*TEP + 0{,}000045\, x*m*TIP*TEP \tag{7}$$

$$SSC = 1{,}889 - 0\, x + 0\, m - 0{,}01836\, TIP + 0{,}07310\, TEP - 0\, x*m - 0\, x*TIP + 0\, x*TEP + 0\, m*TIP - 0\, m*TEP - 0{,}001580\, TIP*TEP + 0\, x*m*TIP + 0\, x*m*TEP - 0\, x*TIP*TEP + 0\, m*TIP*TEP + 0\, x*m*TIP*TEP \tag{8}$$

Minitab 18™ also generated the pareto chart to detect the most sensitive parameters which affect the results. The term significance level (α-level) is used to refer to a pre-chosen probability. Conventionally, 0.05 chosen as α-level which means it was set at a 95% confidence level. Figures 4 and 5 show the pareto chart of the effect of gross power output and SSC by condensing turbine respectively. The most sensitive parameter which affects gross power output is steam fraction (6.36), and the most sensitive parameter which affects SSC is TEP (0.15).

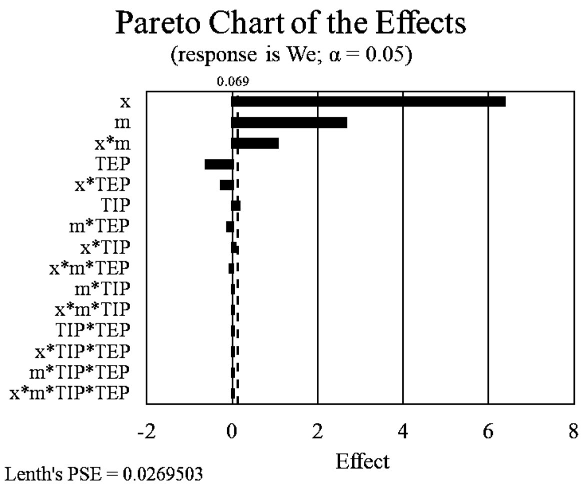


Figure 4. Gross Power Output Pareto Chart.

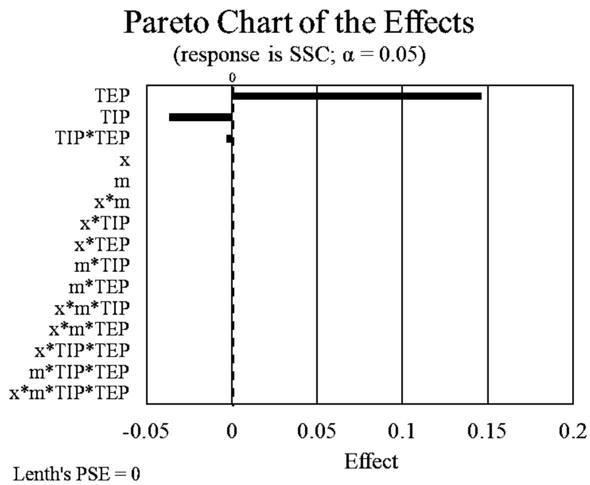


Figure 5. SSC Pareto Chart.

Furthermore, both of first-order polynomial equation of condensing turbine will be run by Monte Carlo simulation. When the calculation converged, the simulation was randomly sampling the probability distribution function as the result of gross power output and SSC. The frequency of random sampling appeared in a certain value range will be calculated automatically by the simulation. The accuracy of a Monte Carlo simulation results is a function of the number of realizations. The confidence limit was chosen on the value of P10, P50, and P90. P10 has the highest confident that means 10% of estimates will be equal or not exceed the P10 estimate. Otherwise, P90 has the lowest confident that means 90% of estimates will be equal or not exceed the P90 estimate. P90 does not mean that the estimate has a 90% chance of occurring. Based on the central limit theorem, P50 estimation has more chance of occurring than the P10 and P90 estimations.

The probabilistic approach was done by Monte Carlo Simulation on the proxy models given in Equation (9) and (10). The cumulative distribution function for gross power output and SSC of condensing turbine is shown in Figures 6 and 7 respectively. The cumulative distribution function; P10, P50, and P90 for the gross power output of condensing turbine is 6.1, 7.9, and 9.9 MWe respectively. The cumulative distribution function; P10, P50, and P90 for SSC of condensing turbine is 1.85, 1.89, and 1.93 (kg/s)/MWe respectively. The P50 estimation has more chance of occurring than the P10 and P90 estimations as shown in Figures 6 and 7.

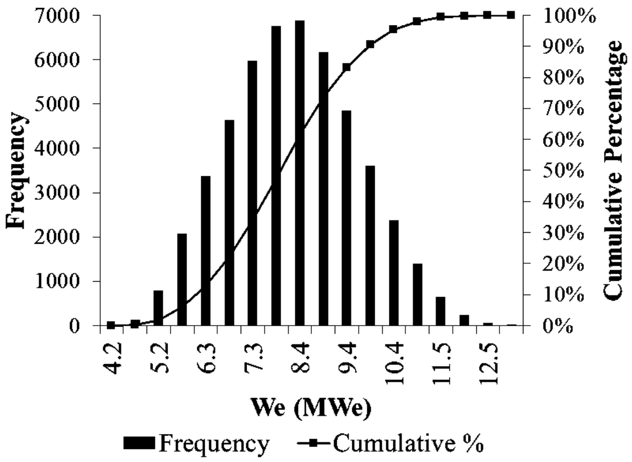


Figure 6. Cumulative distribution function for gross power output.

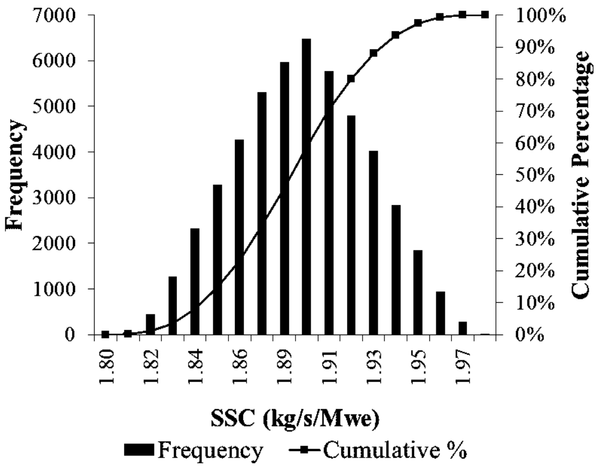


Figure 7. Cumulative distribution function for SSC.

4.2. Economic Assessment

The P10, P50, and P90 values of gross power output for condensing turbine are used as the base case of economic calculation in decline curve analysis. This study assumed the value of decline rate is 3% per year [30]. Integral calculations from 0 to 30 years are performed to calculate the area of each decline rate then multiplied by the electricity price to get the total revenue.

For this study, the electricity price is determined by the P50 values of IRR. Figures 8 and 9 show cumulative distribution function of IRR for condensing turbine. Then, the P10, P50, and P90 of IRR is 12%, 16%, and 21% respectively. The P50 value of condensing turbine is 16% and the ideal IRR desired by the company is 16% [31]. Therefore, the value of the IRR will be set at 16%.

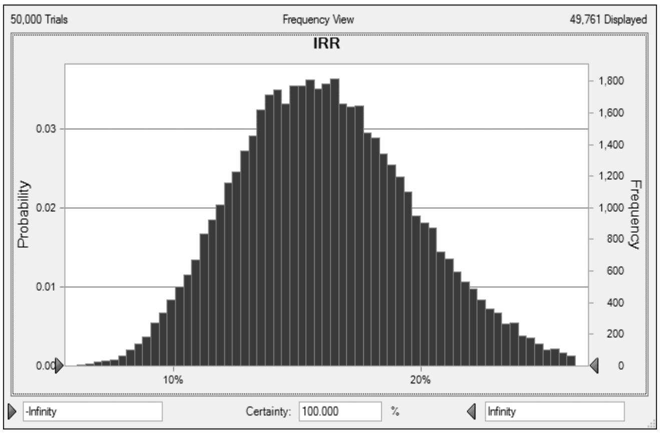


Figure 8. Distribution function of IRR

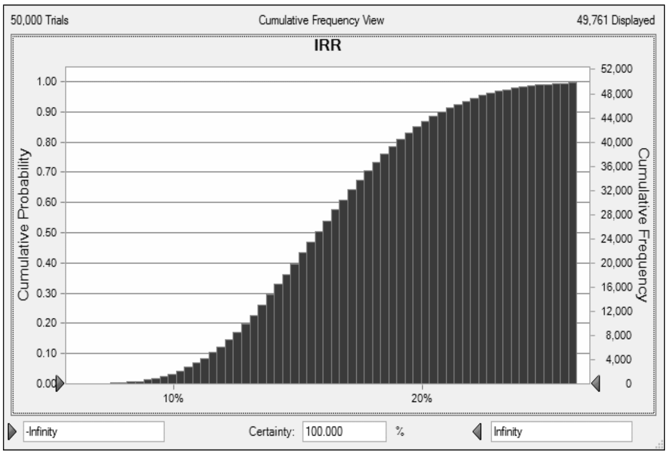


Figure 9. Cumulative distribution function

The calculation of electricity prices was done by adjusting the value of the IRR. The electricity price of condensing turbine is 8.6 US¢/kWh. Then, the calculation of total revenue was done by multiplying the electricity price with the area below the curve. The total revenue earned for 30 years has decreased in value because the calculation of total revenue is based on the decline curve analysis.

Based on the P10, P50, and P90 values, the capacity of condensing turbine is 6, 8, 10 MW respectively. Calculation of capital cost and expense is conducted for 30 years WGU operation. Table 9 show required capital cost and expense of condensing turbine.

Table 9. Capital cost and expense.

Parameters	Minimum	Most-likely	Maximal
Production Well	$ 4,000,000.00	$ 6,000,000.00	$ 8,000,000.00
Injection Well	$ 4,000,000.00	$ 6,000,000.00	$ 8,000,000.00
Power Plant	$ 14,955,067.43	$ 19,820,807.57	$ 24,627,798.49
Transmission line	$ 396,000.00	$ 528,000.00	$ 660,000.00
Total Capital Cost	$ 23,351,067.43	$ 32,348,807.57	$ 41,287,798.49
Operation and Maintenance Cost per Year	$ 1,045,953.61	$ 1,359,393.56	$ 1,682,116.82
Total Expense	$ 31,378,608.15	$ 40,781,806.79	$ 50,463,504.54
Power Generation Capacity	6 MW	8 MW	10 MW
Capital Cost/MW	$ 3,891,844.57	$ 4,043,600.95	$ 4,128,779.85

Figure 10 shows the cumulative cash flow of condensing turbine. The cash flow of all cases will be decreased overtimes because as mentioned above, the total revenue in each year will be decreased while the developer should pay all the bills, such as loan payment, interest, O&M cost, and income tax. From the 21st-year, the cash flow is increased because the loan payment is completed. This result can be used as a consideration for the development of WGU under this condition. On the other hand, the POT is shown at the fifth year.

The probabilistic results calculation was done by the spreadsheet in Microsoft Excel. Figures 11 and 12 show cumulative distribution function of NPV. Then, the P10, P50, and P90 of NPV are $ 1,084,287.00, $ 3,595,430.33, and $ 6,004,139.64 respectively. Based on the NPV criteria, utilization of geothermal field with condensing turbine is interesting to develop.

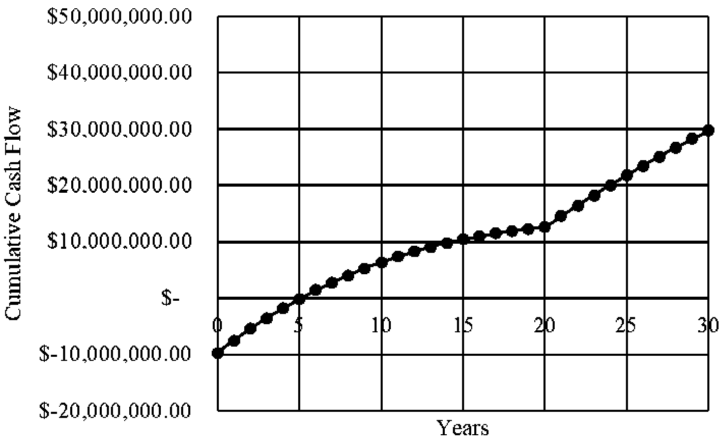


Figure 10. Cumulative cash flow.

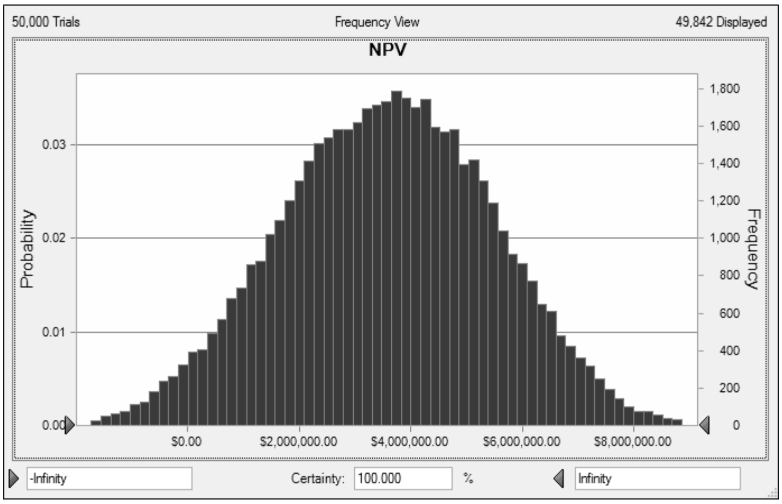


Figure 11. NPV distribution function.

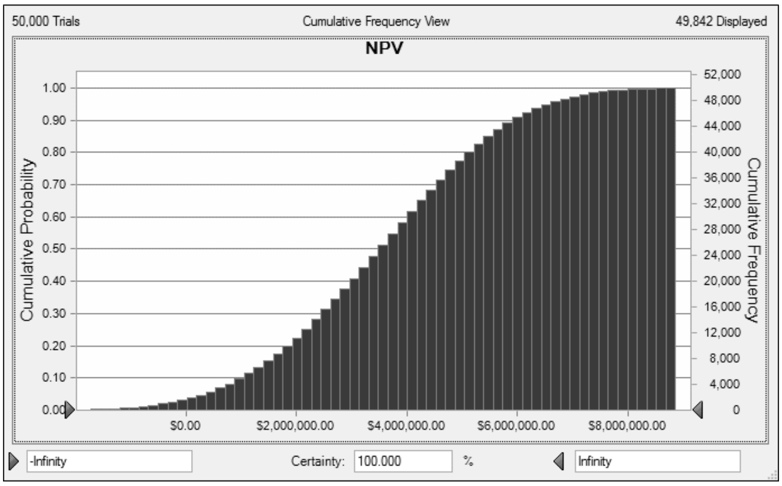


Figure 12. NPV cumulative distribution function.

5. Conclusion
Full factorial experimental design with Monte Carlo simulation for gross power output and Specific Steam Consumption has been successfully applied to calculate and design the condensing turbine. The results of this study are as follow:

1. The result of probability, P10, P50, and P90 of gross power output and Specific Steam Consumption (SSC) are 6.1, 7.9, 9.9 MWe and 1.85, 1.89, 1.93 (kg/s)/MWe respectively.
2. Based on the economic evaluation, condensing turbine gave the P10, P50, and P90 of Internal Rate of Return (IRR) are 12%, 16%, 21% respectively and the P10, P50, and P90 of Net Present Value (NPV) are 1.1 MUSD, 3.6 MUSD, 6.0 MUSD respectively over 30 years of WGU lifetime.

References
[1] Saitet D and Kwambai C 2015 Wellhead generating plants : KenGen experience *Proceedings World Geothermal Congress* 1–6
[2] Sutter J, Kipyego E and Mutai D 2012 The use of portable geothermal wellhead generators as small power plants to accelerate geothermal development and power generation in Kenya *GHC Bull* 27–33
[3] Myers R, Montgomery D and Anderson-Cook C 2001 *Response surface methodology: process and product optimization using designed experiments 3rd ed.* John Wiley and Sons Inc
[4] Ahmad A A, Guwowijoyo F X and Pratama H B 2017 Probabilistic approach: back pressure turbine for geothermal vapor-dominated system *IOP Conf. Ser. Earth Environ. Sci.* **103**
[5] Seidler R, Bücker H M, Padalkina K, Herty M, Niederau J and Marquart G 2015 Optimal experimental design for finding optimally located boreholes in geothermal engineering *World Geotherm. Congr*. 1–3
[6] Quinao J J and Zarrouk S J 2015 Application of experimental design and response surface methods in probabilistic geothermal resource assessment: numerical simulation and volumetric methods *Proceedings World Geothermal Congress Melbourne Australia* 1–12
[7] Ashat A and Pratama H B 2018 Application of experimental design in geothermal resources assessment of Ciwidey-Patuha, West Java, Indonesia *IOP Conf. Ser. Earth Environ. Sci.* **103**
[8] Mchugh-bodylski J 1985 A generic overview of geothermal wellhead generating units *GRC Bull*
[9] Lund J W 2005 100 years of geothermal power product *Proceedings Thirtieth Workshop on Geothermal Reservoir Engineering Stanford University*
[10] Suryadarma, Dwikorianto T, Zuhro A A and Yani A 2010 Sustainable development of the Kamojang geothermal field *Geothermics* **39** 391–9
[11] Hiriart L G 1983 One year experience with portable back-pressure turbines in Los Azufres

Proceedings Ninth Workshop Geothermal Reservoir Engineering Stanford University 275–8
[12] Moya P and Dipippo R 2011 Miravalles PGM-29 wellhead unit Guanacaste Costa Rica: technical and environmental performance assessment present *Short Course Geotherm. Drilling Resour. Dev. Power Plants UNU-GTP LaGeo* 1–13
[13] Kiptanui S and Kipyego E 2016 Viability of wellhead power plants in accelerating geothermal development in Kenya : case of Menengai *Proceedings 6th African Rift Geothermal Conference*
[14] Saptadji N 2018 *Teknik Geotermal* Penerbit ITB Bandung
[15] GeothermEx 1998 Assessment of the geothermal resource in the Karaha Talaga Bodas area *Intern. Rep.*
[16] DiPippo R 2008 *Geothermal power plants* Butterworth-Heinemann Oxford
[17] Long M, Raman R and Harvey W 2012 Staged asset deployment – commercial and technical advantages of using a wellhead generation unit *Proceedings 4th African Rift Geothermal Conference*
[18] Walpole R, Myers R, Myers S and Ye K 2012 *Probability & statistics for engineers and scientists* Pearson Education Inc. Prentice Hall Boston
[19] Spronk J and Hallerbach W 1996 Financial modelling: where to go? with an illustration for portfolio management Eur. *J. Oper. Res.* **99** 113–25
[20] Randle J B 2005 Financial modelling of geothermal projects *Proceeding World Geothermal Congress*
[21] Sarmiento Z F, Steingrímsson B and Axelsson G 2013 Volumetric resource assessment Present. *Short Course Concept. Model Geotherm. Syst. UNU-GTP LaGeo* 1–15
[22] Ministry of Finance Regulation 2010 *Pemberian fasilitas perpajakan dan kepabeanan untuk kegiatan pemanfaatan sumber energi terbarukan* Indonesia: Ministry of Finance Regulation No. 21 of 2010
[23] Serdjuk M, Dumas P, Angelino L and Tryggvadóttir L 2013 *Geolec: geothermal investment Guide* Eur. Intell. Energy Eur. Program Eur. Union
[24] Quinlivan P, Batten A, Wibowo M, Hinchliffe S, Rahayu D, Yahmadi A and Tondang H 2015 Assessing geothermal tariffs in the face of uncertainty: a probabilistic approach *Proceedings World Geothermal Congress*
[25] Indonesia Constitution 2008 *Perubahan keempat atas undang-undang nomor 7 tahun 1983 tentang pajak penghasilan* Indonesia: constitution No.36/2008
[26] Arps J J 1945 Analysis of decline curves *AIME* **160** 228–47
[27] Purwanto E H, Suwarno E, Lukman R F and Herdiyanto B 2018 Geothermal drilling in Indonesia: a review of drilling implementation evaluation of well cost and well capacity *Proceedings The 6th Indonesia International Geothermal Convention & Exhibition* Jakarta Indonesia
[28] Sanyal S K 2005 Cost of geothermal power and factors that affect it *Proceedings World Geothermal Congress*
[29] Asian Development Bank and World Bank 2015 *Unlocking Indonesia's geothermal potential*
[30] Purwaningsih F O, Husnie R, Afuar W and Abdurrahman G 2018 Make-up wells drilling cost in financial model for a geothermal project *IOP Conf. Ser. Earth Environ. Sci.* **103**
[31] Poernomo A 2012 23 *Proyek panas bumi terancam merangkak* Ber. Satu