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Comparison Between Three-Level Box-Behnken Design and Three-Level Full Factorial Design for Probabilistic Resource Assessment: A Case Study in Atadei Geothermal Field, Indonesia

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ABSTRACT

The assessment of resources in the geothermal green field is likely to face some difficulties due to the limited number of data and the existence of data uncertainty that will directly have an impact on the accuracy of the determination of resources. Therefore, it is necessary to do probabilistic resource potential assessments that consider the uncertainty of the data using the experimental design method. In this paper, we will explore a comparative study of a three-level design of Box-Behnken Design (BBD) and Full Factorial Design (FFD) using the Atadei geothermal numeric model to obtain probabilistic resource assessment results. The purpose of this study was to determine how the results of the Experimental Design (ED) and Surface Response Method (RSM) were based on the BBD and the FFD method on the results of probabilistic resource assessments. BBD and FFD are used to construct 27 and 81 trial cases, for each case four parameters such as permeability, porosity, liquid saturation, and location of the feed zone with three levels, namely minimum, most likely, and maximum are used for calculation. The prediction results of numerical simulations of the Atedai field for various cases are used to construct polynomial functions (proxy equations) and then applied to Monte Carlo simulations to generate probabilistic distribution of potential power outputs. Both methods have succeeded in estimating more robust electricity potential which covers the entire range of values of important reservoir parameters. Deep analysis of the proxy equation based on R-square (R^2) and error of the regression (S) for both design shows that BBD has more robust results rather than FFD. The probabilistic power capacity of Atadei geothermal field using Monte Carlo based on three-level Box-Behnken Design for 30 years production for P10, P50, and P90 are 11.7 MW, 18.2 MW, and 25.6 MW respectively.

1. INTRODUCTION

Energy reserve is the most important aspect in geothermal development. The amount of energy reserve in geothermal will affect the development strategy. Therefore, reserve calculation is an important thing to do. The best method to calculate the reserves and commonly used at this time was numerical simulation method. However, data input for numerical simulation in geothermal has a high uncertainty with a low level of confidence. Resource assessment needs to be done using experimental design (ED) and response surface method (RSM) combined with a probabilistic approach that starts with numerical outputs to quantify the uncertainty of reservoir parameters.

Probabilistic resource assessment is the practice of generating the probability distribution function of a geothermal systems' resource size or resource potential based on the uncertainties of the available reservoir information (Quinao and Zarrouk, 2015). The most common application of probabilistic resource assessment is carried out with the heat stored method through the Monte Carlo simulation. Probabilistic resource assessment with heat stored method has been carried out by several researchers; Manggala Putra et al. (2019) in Arjuno-Welirang geothermal field, Hidayat et al. (2018) in Kerinci geothermal field, Pradhipta et al. (2019) in Mataloko geothermal field, and Kurniawan et al. (2019) in Ulumbu geothermal field. The range of parameter values in these method (heat stored) covers the range of uncertainty for that particular variable (Ashat and Pratama, 2017).

The experimental design based on production is preferred than the heat stored method to provide a better estimate in the resource assessment process (Ashat et al., 2019). Experimental design is a systematic way of simultaneously testing multiple variables that affect the response (Quinao and Zarrouk, 2015). Experimental design began to be applied in the geothermal industry, which is used to calculate the energy reserves (Ciriaco et al., 2018; Quinao and Zarrouk, 2014; Quinao and Zarrouk, 2015; Quinao and Zarrouk, 2018; Ashat and Pratama, 2017, Ansari and Hughes, 2016; Pasikki et al., 2016; Prabata et al., 2018; Kurniawan et al., 2018).

This study aimed to build a numerical simulation of Atadei geothermal field and to perform the experimental design (ED) and response surface method (RSM) for probabilistic resource assessment. A comparative study between a three-level design of Box-Behnken Design (BBD) and Full Factorial Design (FFD) using the Atadei geothermal numeric model to obtain probabilistic resource assessment results.

2. EXPERIMENTAL DESIGN AND RESPONSE SURFACE METHOD

The main objectives of experimental design and response surface method when using reservoir simulations are the following (Quinao and Zarrouk, 2015):

- To systematically design and perform simulation experiments on the reservoir model in order to understand the relationship between uncertain parameters and performance-related responses, and
- To fit a response surface (proxy polynomial) on the simulation experiment result in order to describe the performance-related responses as a polynomial function of the uncertain parameters.

If all parameters are assumed to be measurable, the response surface can be expressed as follow:

$$Y = f\ (x_1, x_2, x_3, \dots, x_k) \quad (1)$$

Where Y is the answer to the system, - and x_i the parameters of action called factors (Aslan and Cebeci, 2007).

Usually a second-order model is utilized in response surface methodology (Mäkelä, 2017):

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \varepsilon \quad (2)$$

Where β_0 describes the average value of Y, β_i, β_{ij}, and β_{ii} the first order, interaction and quadratic coefficient, respectively, x_i the coded factors and ε the model residual.

This study used two types of experimental design and response surface method in order to make a comparison between both designs, which is three-level Full Factorial Design and Box-Behnken Design. There are four parameters used in this study which has high uncertainty in the model. The parameters that have high uncertainty in the model are porosity, permeability, liquid saturation, and location of the feed zone. Figure 1 shows the geometry of three-level Full Factorial Design, while Figure 2 shows the geometry of Box-Behnken Design.

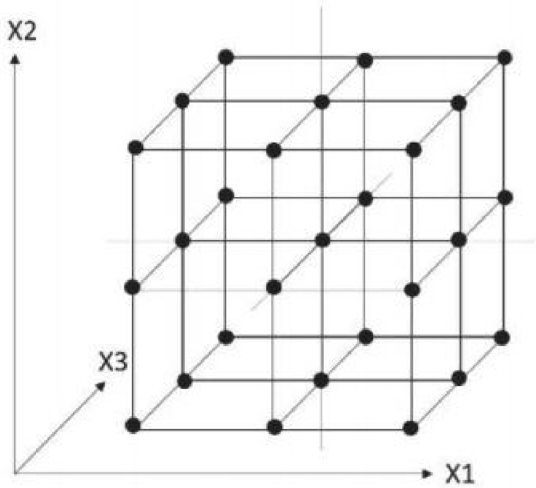

Figure 1: The geometry of three-level Full Factorial Design (Fukuda et al., 2018)

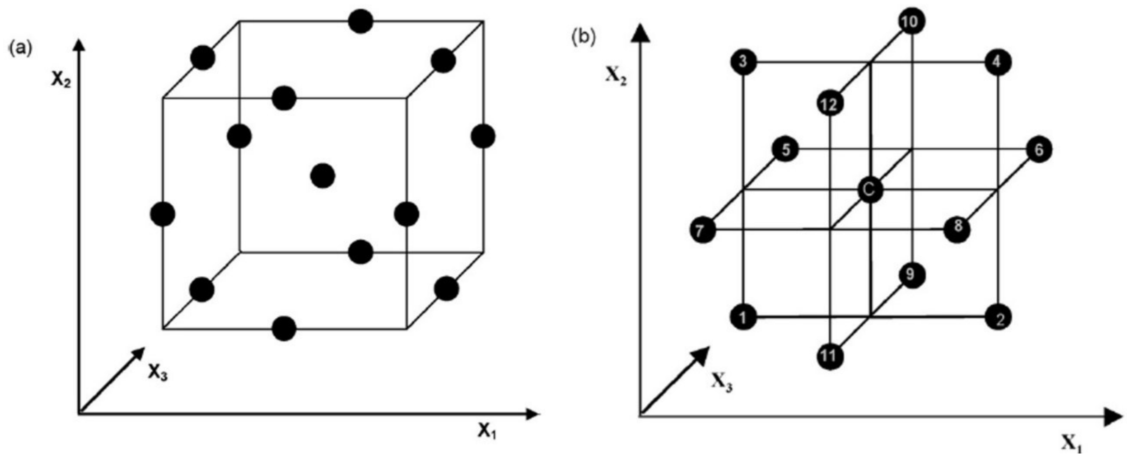

Figure 2: The geometry of Box-Behnken Design. (a) A cube that consists of the central point and the middle point of the edges. (b) A figure of three interlocking 2^2 factorial designs and a central point (Ferreira et al., 2007).

3. ATADEI GEOTHERMAL FIELD

Atadei geothermal field is located in Lembata Regency, East Nusa Tenggara, Indonesia. The location of Atadei geothermal field is shown in Figure 3, and the prospect area is considered as located in a remote area. To reach Atadei from Jakarta would take around two consecutive days, and this is counted as one of the challenges found in developing this field. PT. PLN (a state-owned company), since April 2017 has been the concession owner of this field based on SK-permits No. 1894 K/30/MEM/2017.

Figure 3: The location of Atadei Geothermal field (Supijo et al., 2018).

3.1 Atadei Conceptual Model

The conceptual model was updated by (Supijo et al., 2018) shown in Figure 4. The conceptual model designed based on comprehensive geoscience reviews and numerical model approach. It appears that hot geothermal fluid is upwelling from the deep part of the Watuwawer caldera. The deep leakage of fracture permeability from Watuwawer Fault and Lewo-Kebingin Fault control the flows of hot fluids-in which it ascends through the given vertical permeability-with some fluids flow laterally to the Southeast until rising to the surface through Mauraja Fault as outflow. In contrary to the initial model, there is a change in determining the depth of the top reservoir as the updated model has followed the interpretation of Magnetotelluric data rather than DC-Resistivity in which Nanlohy et. al (2003) had followed. It stated that in general top of reservoir of Atadei geothermal area is situated around the depth of -800 masl. The only exception applied for Watuwawer area in which the reservoir reached the depth of -700 masl.

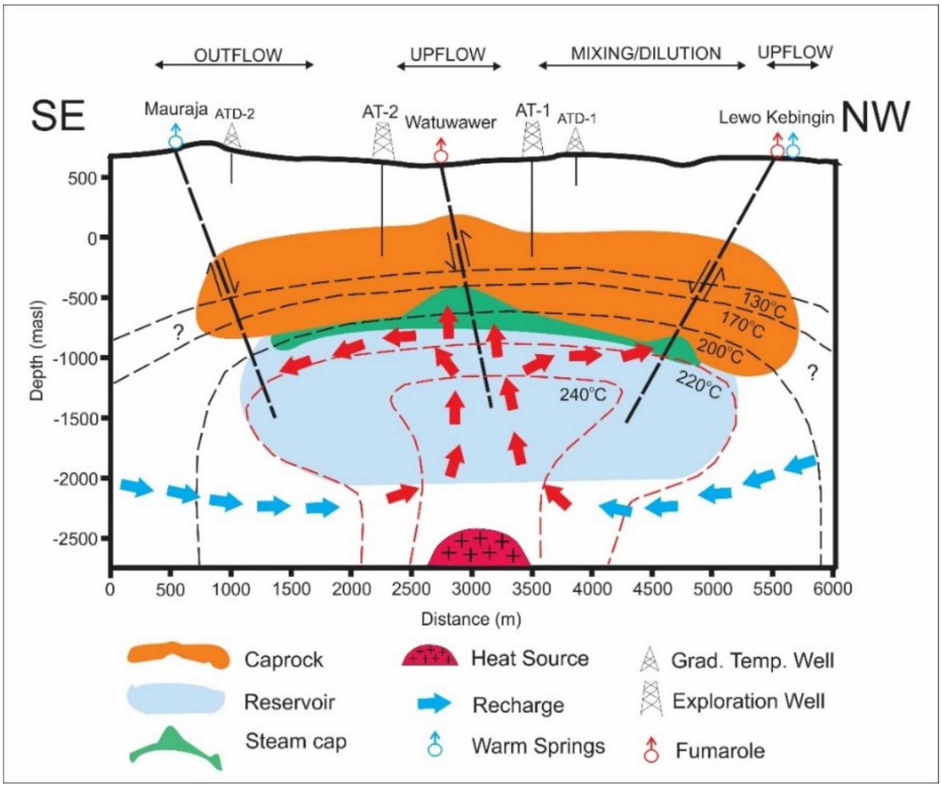

Figure 4: Conceptual model of Atadei geothermal system (Modified from Supijo et al., 2018).

3.2 Atadei Numerical Model

Based on the conceptual model of Figure 4, a numerical model of the Atadei geothermal system was developed. The modeling process was carried out by using a pre- and post-processor of TOUGH2. The grid of the model is rotated at 127° to the East to accommodate the material assignment to be necessary for an arrangement with the alignment of the conceptual model. It is covering a total area of 6.4 km x 5 km or equal to 32 km^2 and a total thickness of 3.45 km (i.e., from 950 masl to -2500 masl). The horizontal dimension of grid blocks varies from the smallest 100 m x 100 m to the most significant 500 m x 500 m, and the smallest grid blocks are used near the reservoir area, wells, and faults to increase the modeling accuracy on that area. The model is divided into 13 layers with some of the top layers follow the real topographical condition. The total number of grid blocks is 22,560 by using a rectangular grid type.

The initial condition is needed to input the initial temperature and pressure for each grid-block on the model to fasten the process of running the model. At the initial condition, the normal gradient is used for both temperature and pressure. Meanwhile, the top layer is set to constant at the atmospheric conditions with the pressure is set at 1E-05 Pa and the temperature is at 25^{O}C.

During the numerical modeling, determining the permeability structure is the essential step to be iteratively adjusted until the natural state condition was achieved. The iterative process is done by several trial and errors. The permeability structure used in the final modeling is shown in Table 1 and its distribution to the grid model, also shown in Figure 5.

Table 1. Material properties

Material	K_{xy} (mD)	K_z (mD)	Color
ATM	10	10	
GW	0.002	0.002	
CAPR	0.00001	0.00001	
BOUND	0.00005	0.00001	
HEAT	100	100	
RES1	60	30	
RES2	40	30	
RES3	20	20	
RES4	10	10	
RES5	70	70	
RESMT	60	30	
FAULT	30	30	
BASE	3	3	
FAUL1	30	20	
TRNS	0.001	0.001	

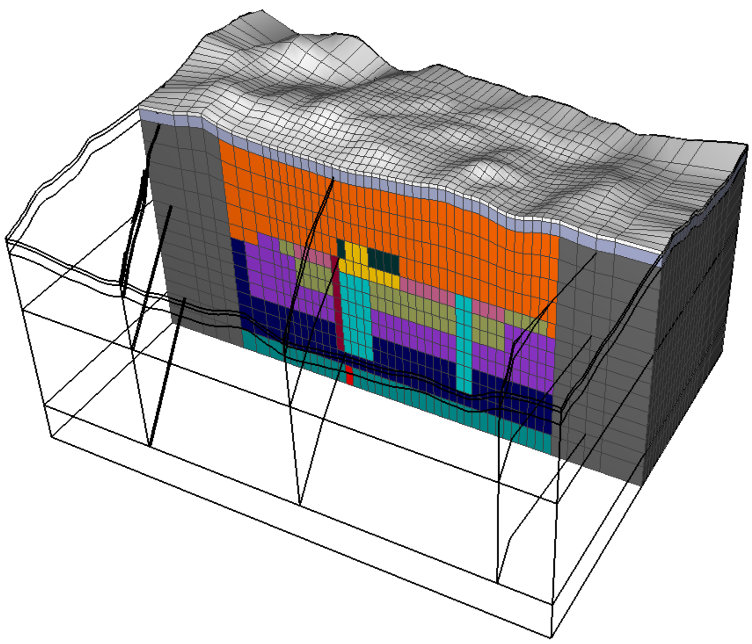

Figure 5: Material assignment to the model.

During the initial state calibration, also called natural state modeling, the computer model was run until natural steady-state conditions were reached. The results were then compared against actual wells temperatures and reservoir temperature estimation obtain from geothermometer. The proper fit between model results and field observation data, the permeability structures was adjusted in an iterative process. There is only one observation well available to match the model, and it is obtained from AT-1. The dummy wells in Atadei area were also used to match the reservoir temperature by comparing with the temperature estimation obtained from the ammonia geothermometer, considering well AT-1 was not reached the depth of the reservoir. Figure 6 indicates the temperature matching of AT-01. It shows a good alignment between the actual and the modeled temperature.

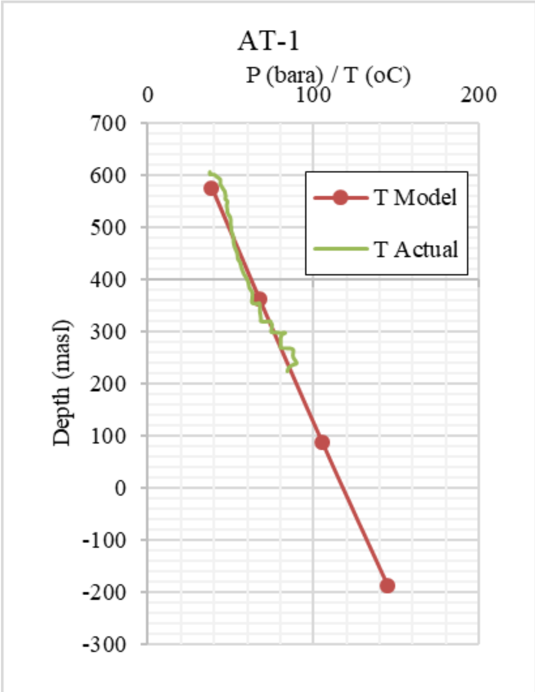

Figure 6: AT-1 temperature matching.

One of the crucial driver outcomes of the reservoir numerical modeling is the simulation of heat and mass flow within the system, as illustrated in Figure 7. It concludes the whole fluid flow process from the upwelling geothermal heat flow beneath the Watuwawer caldera in which the hot fluids ascend directly through the given vertical fracture permeability later emerge as upflow manifestation in Watuwawer, Lewo Keba and Lewo Kebingin. The residual fluids circulate within permeable zones as the hot fluid with lighter in density ascends until it reaches the impermeable layers where heat losses occur resulting in some cooling fluids descending back to the reservoir and some other flow laterally until it emerges as outflow manifestation in the surface in Mauraja and Lewo Kebingin.

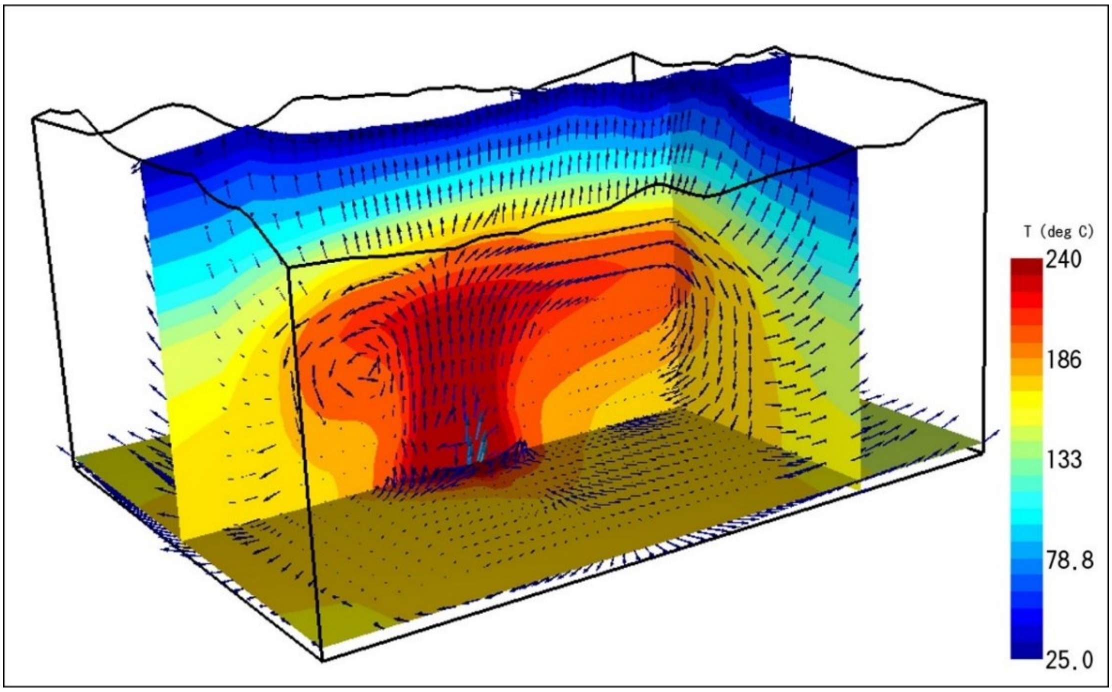

Figure 7: Heat and mass transfer in a vertical and horizontal slice of the numerical model.

4. EXPERIMENTAL DESIGN AND RESPONSE SURFACE METHOD ON THE ATADEI MODEL

Experimental design and response surface method is a systematic approach to simulate a probabilistic resource assessment (Ashat et al., 2019). The experimental design and response surface method concept was applied in Atadei reservoir model in order to analyze the dependency from uncertain reservoir parameters to know the amount of production (MW) for 30 years. Furthermore, it also has a purpose to construct polynomial functions (proxy equations) based on reservoir simulation results through the Monte Carlo simulation. The simulation experiment requires choosing the parameters that will be included in the investigation.

There are four main parameters were investigated: porosity (POR), permeability (PERM), liquid saturation (SW), and the location of the feed zone (FZ). The three-level Full Factorial design and Box-Behnken design, each level namely minimum, most likely, and maximum, which notated in -1, 0, and +1. The minimum and maximum value from porosity and permeability are ±20% deviations from initial condition of material properties (Ashat et al., 2019). Due to the occurrence of a steam cap in the model, liquid saturation for the most likely value is 40%, the minimum value is 30%, and the maximum value is 50%. The location of the feed zone separated in three locations, most likely value located in the two-phase zone, minimum value located in the steam zone, while the maximum value located in the brine zone. The sensitivity for each parameter is shown in Table 2.

Table 2. Uncertain model parameters used in the experimental design and response surface method.

Parameter	Minimum (-1)	Most likely (0)	Maximum (+1)
Porosity (POR)	-20%	Initial Condition	+20%
Permeability (PERM)	-20%	Initial Condition	+20%
Liquid Saturation (SW)	0.3	0.4	0.5
Feed Zone (FZ)	-600 s/d -800 masl	-800 s/d -1000 masl	-800 s/d -1200 masl

Resource assessment using experimental design and response surface method is done by producing wells at certain wellhead pressure. The assigning of dummy wells aims to produce all mass in the reservoir in order to calculate the power capacity. The reservoir simulation was run equally distributing using well on deliverability method with PI 1.0E-12 m^3 and WHP 10 bar. Total dummy production wells are 143 wells with targeting the steam zone, two-phase zone, and brine zone with temperature more than 200^{o}C in the reservoir, as illustrated in Figure 8.

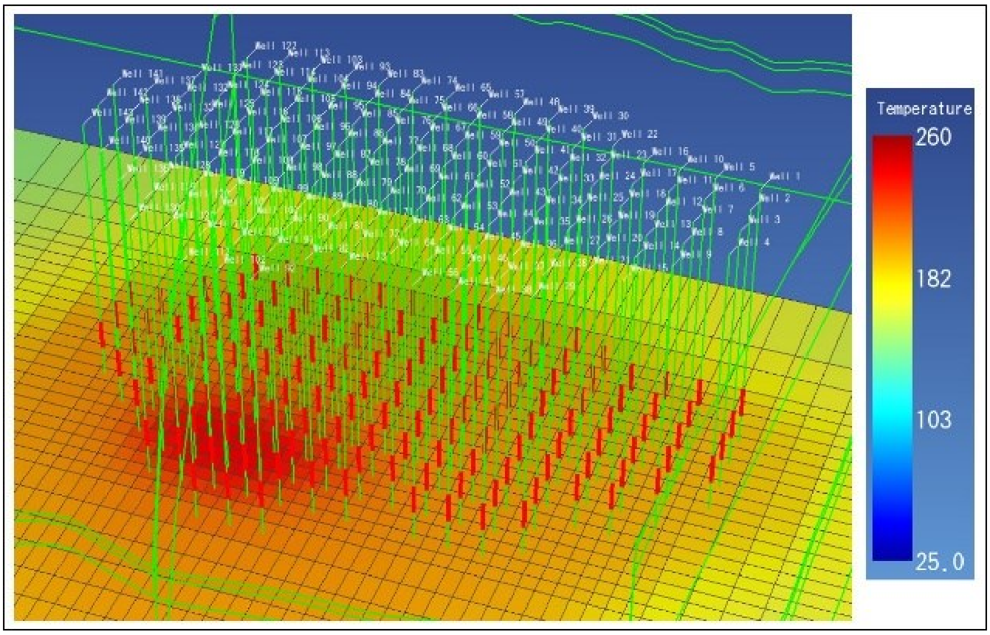

Figure 8: Location of dummy production wells.

The electric potential in MW, the following equation was used (Quinao and Zarrouk, 2015; Ashat and Pratama, 2017)

$$MW_e = \frac{\sum_{m=1}^{L} m \times \Delta t}{L \times SSC} \tag{3}$$

Where MWe is the power capacity in MW, m is the produced steam (kg/s), Δt is the delta time at the simulation (years), L is the project time (years), and SSC is the specific steam consumption (kg/s/MW).

A three-level of Full Factorial and Box-Behnken combination was automatically designed using Minitab 17. With four parameters at three levels, total combination for Full Factorial Design will be 81 runs and Box-Behnken Design will be 27 runs. Table 3 summarized the entire three-level Full Factorial Design (FFD) and Box-Behnken Design (BBD) with four parameters.

Table 3. Combination of three-level Full Factorial Design with four parameters.

POR	PERM	SW	FZ	RunOrder		POR	PERM	SW	FZ	RunOrder	
				FFD	BBD					FFD	BBD
-1	1	0	1	1		1	0	-1	1	42	
0	0	-1	-1	2	26	0	0	1	-1	43	21
-1	1	-1	0	3		0	1	1	0	44	27
-1	1	0	-1	4		0	1	-1	-1	45	
-1	-1	1	1	5		0	-1	-1	1	46	
1	0	0	1	6	20	0	1	0	-1	47	1
1	1	-1	0	7		0	0	-1	1	48	22
0	1	1	-1	8		1	-1	-1	0	49	
-1	1	-1	1	9		1	1	0	0	50	15
-1	1	1	-1	10		1	1	0	1	51	
1	0	1	0	11	2	0	0	1	0	52	
-1	0	1	1	12		0	0	-1	0	53	
-1	-1	0	-1	13		-1	-1	1	0	54	
0	-1	-1	0	14	25	0	-1	1	0	55	4
1	-1	0	-1	15		1	1	1	-1	56	
1	1	1	0	16		-1	0	-1	0	57	11
-1	0	0	-1	17	16	0	-1	0	0	58	
-1	1	-1	-1	18		0	-1	-1	-1	59	
1	1	0	-1	19		1	0	0	-1	60	23
-1	-1	-1	0	20		-1	0	-1	-1	61	
-1	-1	0	0	21	14	-1	0	-1	1	62	
0	1	-1	1	22		0	0	0	1	63	
1	0	1	-1	23		1	-1	0	0	64	
0	-1	0	-1	24	5	1	-1	0	0	65	19
0	-1	0	-1	25		1	0	-1	-1	66	
1	-1	-1	1	26		1	-1	1	-1	67	
1	1	-1	-1	27		-1	0	0	1	68	17
0	-1	1	1	28		-1	0	1	-1	69	
0	1	0	0	29		-1	-1	-1	-1	70	
0	1	0	1	30	18	1	0	1	1	71	
0	0	1	1	31	9	1	-1	1	0	72	
1	1	-1	1	32		-1	-1	1	-1	73	
0	0	0	-1	33		0	0	0	0	74	3, 8, 10
1	0	0	0	34		1	0	-1	0	75	7
-1	1	0	0	35	24	-1	1	1	1	76	
-1	-1	-1	1	36		0	-1	0	1	77	13
0	1	1	1	37		1	-1	1	1	78	
0	1	-1	0	38	6	-1	0	0	0	79	
1	-1	-1	-1	39		-1	1	1	0	80	
1	1	1	1	40		1	-1	0	1	81	
-1	0	1	0	41	12						

The model parameters then are changed according to the Full Factorial Design and Box-Behnken Design for each combination. The model was run until steady-state conditions to recalibrate the PT well in order to determine whether the model still in natural state conditions or model are not involved in the next process. After reaching natural state conditions, the model then produced for 30 years for each combination of three-level Full Factorial Design and Box-Behnken Design. The results of Atadei resource assessment for 30 years of steam production with 2 kg/s/MW of SSC for three-level Full Factorial Design and Box-Behnken Design shown in Table 4.

Table 4. Compilation of power capacity results based on three-level Full Factorial Design (FFD) and Box-Behnken Design (BBD)

RunOrder		MW	RunOrder		MW	RunOrder		MW
FFD	BBD		FFD	BBD		FFD	BBD	
1		36	28		29	55	4	18
2	26	7	29		21	56		9
3		21	30	18	35	57	11	19
4		8	31	9	32	58		18
5		28	32		38	59		8
6	20	34	33		8	60	23	8
7		21	34		20	61		8
8		9	35	24	21	62		33
9		36	36		29	63		33
10		9	37		36	64		28
11	2	19	38	6	21	65	19	18
12		32	39		7	66		7
13		8	40		36	67		9
14	25	18	41	12	19	68	17	32
15		8	42		34	69		9
16		21	43	21	9	70		8
17	16	8	44	27	21	71		33
18		8	45		7	72		18
19		8	46		30	73		9
20		18	47	1	8	74	3, 8, 10	19
21	14	17	48	22	34	75	7	20
22		37	49		18	76		35
23		9	50	15	21	77	13	29
24	5	8	51		37	78		29
25		9	52		19	79		19
26		30	53		19	80		20
27		7	54		17	81		30

Based on a Pareto chart plot carried out on the three-level Full Factorial Design results, it shows that only location of the feed zone among the parameters tested has a significant effect on the 30 years power capacity of the Atadei geothermal field. The Pareto chart shows that porosity and liquid saturation relatively have a steady effect on the 30 years of power capacity. The Pareto chart is shown in Figure 9. Figure 10 shows a Surface plot based on Box-Behnken Design results. Figure 10 indicates that the interaction between permeability (PERM) and location of the feed zone (FZ) is the most significant parameter that controls the fluctuate of power capacity output.

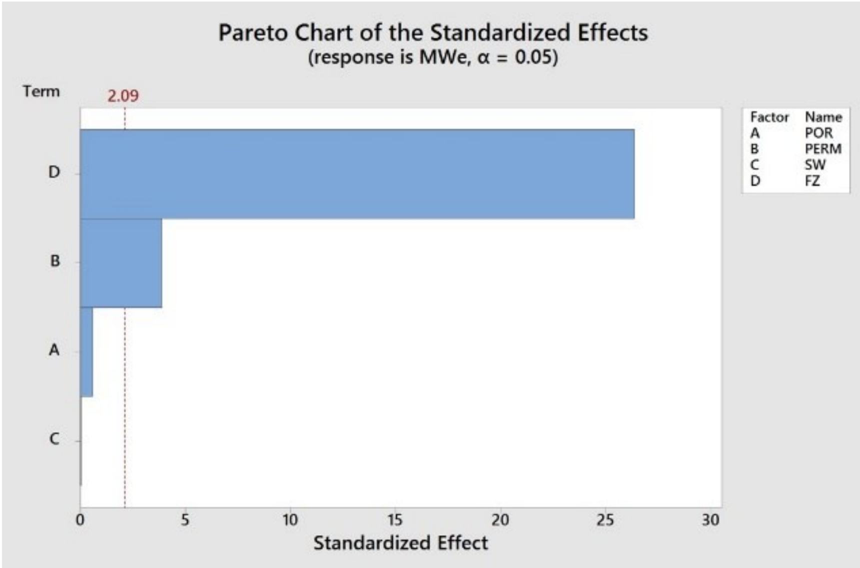

Figure 9: Pareto chart of three-level Full Factorial Design results.

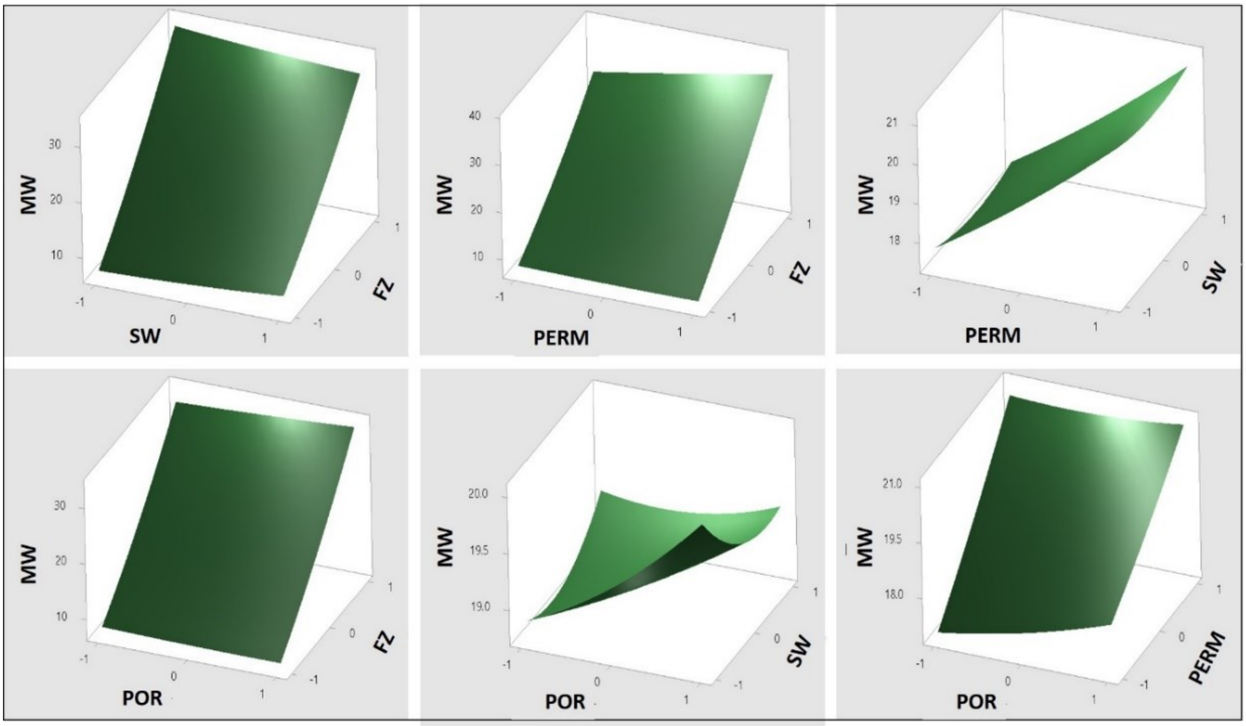

Figure 10: Surface plot of Box-Behnken Design results.

4.1 Three-level Full Factorial Design Regression

The second-order regression analysis based on three-level Full Factorial Design is shown in table 5. The regression equation of power capacity as a function of four independent parameters are the results in this study. A three-level Full Factorial proxy model using -1, 0, and +1 parameters to generate the power capacity responses for Atadei model shown in Equation 4.

Table 5. Second-order regression analysis based on three-level Full Factorial Design results.

Term	*Coef*
Constant	19.000
POR	0.3333
PERM	1.6667
SW	-0.0833
FZ	12.4167
POR*POR	0.125
PERM*PERM	0.125
SW*SW	0.250
FZ*FZ	1.250
POR*PERM	-0.250
POR*SW	-0.250
POR*FZ	0.500
PERM*SW	0.000
PERM*FZ	1.750
SW*FZ	-1.000

$$MWe = 19.000 + 0.333 \times POR + 1.6667 \times PERM - 0.0833 \times SW + 12.4167 \times FZ + 0.125 \times POR^2 + 0.125 \times PERM^2 + 0.250 \times SW^2 + 1.250 \times FZ^2 - 0.250 \times POR \times PERM - 0.250 \times POR \times SW + 0.500 \times POR \times FZ + 0.000 \times PERM \times SW + 1.750 \times PERM \times FZ - 1.000 \times SW \times FZ \quad (4)$$

Equation 4 then tested for validity to determine the alignment of the regression equation with the model results from the reservoir simulation. Figure 11 shows the comparison between the second-order regression equation of three-level Full Factorial Design and the model results. It is showing a good alignment between the regression results and the model results. This can be seen from the standard error of the regression (S), which has a value of 1.44 MWe. Furthermore, the second-order regression indicates a high R-square (R^2) value of 97.78%

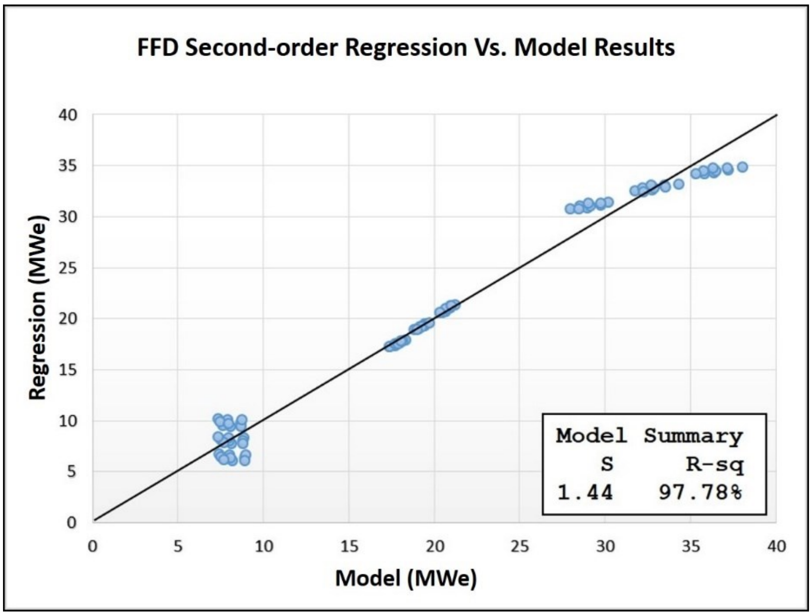

Figure 11: Second-order regression of three-level Full Factorial design results versus model results.

4.2 Box-Behnken Design Regression

The second-order regression analysis based on Box-Behnken is shown in table 6. The regression equation of power capacity as a function of four independent parameters are the results in this study. A Box-Behnken proxy model using -1, 0, and +1 parameters to generate the power capacity responses for Atadei model shown in Equation 5.

Table 6. Second-order regression analysis based on Box-Behnken Design results.

Term	*Coef*
Constant	19.000
POR	0.3333
PERM	1.6667
SW	-0.0833
FZ	12.4167
POR*POR	0.125
PERM*PERM	0.125
SW*SW	0.250
FZ*FZ	1.250
POR*PERM	-0.250
POR*SW	-0.250
POR*FZ	0.500
PERM*SW	0.000
PERM*FZ	1.750
SW*FZ	-1.000

$$MWe = 19.000 + 0.333 \times POR + 1.6667 \times PERM - 0.0833 \times SW + 12.4167 \times FZ + 0.125 \times POR^2 + 0.125 \times PERM^2 + 0.250 \times SW^2 + 1.250 \times FZ^2 - 0.250 \times POR \times PERM - 0.250 \times POR \times SW + 0.500 \times POR \times FZ + 0.000 \times PERM \times SW + 1.750 \times PERM \times FZ - 1.000 \times SW \times FZ \quad (5)$$

Equation 5 then tested for validity to determine the alignment of the regression equation with the model results from the reservoir simulation. Figure 12 shows the comparison between the second-order regression equation of three-level Full Factorial Design and the model results. It is showing a good alignment between the regression results and the model results. This can be seen from the standard error of the regression (S), which has a value of 0.27 MWe. Furthermore, the second-order regression indicates a high R-square (R^2) value of 99.72%

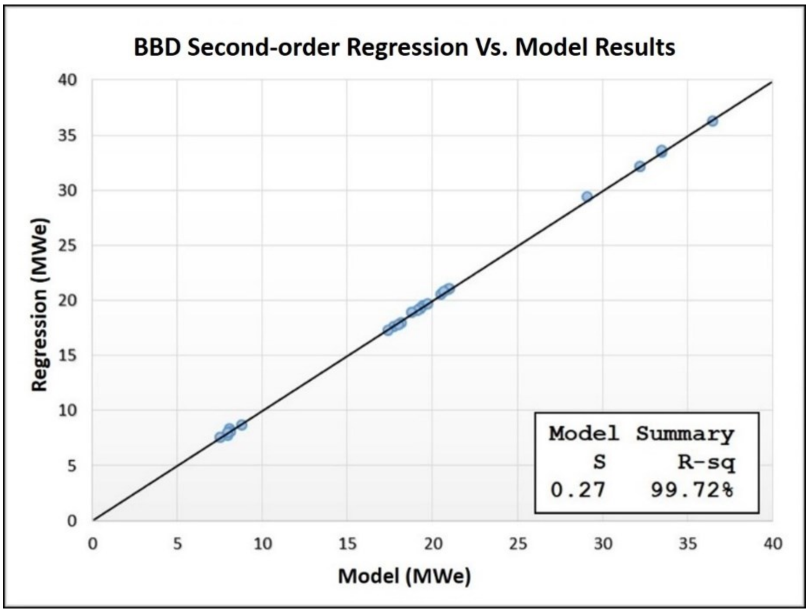

Figure 12: Second-order regression of Box-Behnken Design results versus model results.

Comparative results between three-level Full Factorial Design and Box-Behnken Design shows that Box-Behnken Design has a good result rather than three-level Full Factorial Design. This can be seen from error of regression (S) of Box-Behnken Design is lower than Full Factorial Design, and R-square (R^2) value higher than Full Factorial design. This results also indicated that Box-Behnken Design is more efficient rather than three-level Full Factorial Design, with a smaller run, Box-Behnken can produce a good fit proxy model.

4.3 Integrated to Monte Carlo Simulation for Probabilistic Distribution of Power Capacity

Based on comparative results, Box-Behnken Design was chosen to be integrated into the Monte Carlo simulation to calculate the probabilistic power capacity of Atadei geothermal field power capacity. Monte Carlo simulation with 60,000 random number was carried out on the proxy model, using the probability distributions of the individual parameter as described in Table 2. The result is a probability distribution function of the power capacity covering the full range of possible outcomes. The proxy model was then applied to calculate the range of possible values for P10, P50, and P90 of MW. The cumulative distribution for 30 years of steam production of the power capacity shown in Figure 13. The P10, P50, and P90 are 11.7 MW, 18.2 MW, and 25.6 MW, respectively.

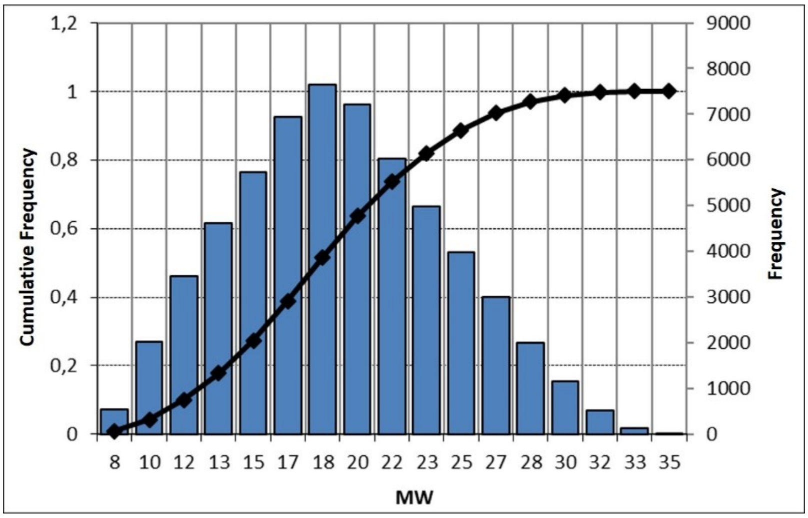

Figure 13: Monte Carlo simulation results with histogram and cumulative distribution functions based on the proxy model of Box-Behnken Design.

5. CONCLUSION

1. The numerical simulation with experimental design and response surface method has successfully applied for Atadei geothermal green field.
2. Comparative results between three-level Full Factorial Design and Box-Behnken Design shows that Box-Behnken Design has a good result rather than three-level Full Factorial Design. This can be seen from error of regression (S) of Box-Behnken Design is lower than Full Factorial Design, and R-square (R2) value higher than Full Factorial design. This results also indicated that Box-Behnken Design is more efficient rather than three-level Full Factorial Design, with a smaller run, Box-Behnken can produce a good fit proxy model
3. The probabilistic power capacity using Monte Carlo based on Box-Behnken design for 30 years production for P10, P50, and P90 are 11.7 MW, 18.2 MW, and 25.6 MW respectively

REFERENCES

Ansari, E., & Hughes, R. (2016). Response surface method for assessing energy production from geopressured geothermal reservoirs. *Journal of Geothermal Energy*, *4*(1).

Ashat, A., & Pratama, H. B. (2017). Application of experimental design in geothermal resources assessment of Ciwidey-Patuha, West Java, Indonesia. *Proceedings of 6th ITB International Geothermal Workshop (IIGW) 2017.*

Ashat, A., Pratama, H. B., & Itoi, R. (2019). Comparison of resource assessment methods with numerical reservoir model between heat stored and experimental design: Case study Ciwidey-Patuha geothermal field. *Proceedings of 7th ITB International Geothermal Workshop (IIGW) 2018.*

Aslan, N., & Cebeci, Y. (2007). Application of Box-Behnken design and response surface methodology for modeling of some Turkish coals. *Journal of Fuel*, *86*(1–2), 90–97.

Ciriaco, A. E., Zarrouk, S. J., & Zakeri, G. (2018). Probabilistic Resource Assessment Using Experimental Design and Second Order Proxy Model : Rotorua Geothermal System , New Zealand. *Proceedings of 40th New Zealand Geothermal Workshop 2018.*

Ferreira, S. L. C., Bruns, R. E., Ferreira, H. S., Matos, G. D., David, J. M., Brandao, G. C., … dos Santos, W. N. L. (2007). Box-Behnken design: An alternative for the optimization of analytical methods. *Journal of Analytica Chimica Acta*.

Fukuda, I. M., Pinto, C. F. F., Moreira, C. D. S., Saviano, A. M., & Lourenço, F. R. (2018). Design of experiments (DoE) applied to pharmaceutical and analytical quality by design (QbD). *Brazilian Journal of Pharmaceutical Sciences*, *54*(Special Issue), 1–16.

Hidayat, I., Sutopo, & Pratama, H. B. (2018). Probabilistic approach of resource assessment in Kerinci geothermal field using numerical simulation coupling with monte carlo simulation. *Proceedings of 6th ITB International Geothermal Workshop (IIGW) 2017.*

Kurniawan, I., Sutopo, S., Pratama, H. B., & Adiprana, R. (2019). A natural state model and resource assessment of Ulumbu Geothermal field. *Proceedings of 7th ITB International Geothermal Workshop (IIGW) 2018.*

Mäkelä, M. (2017). Experimental design and response surface methodology in energy applications : A tutorial review. *Journal of Energy Conversion and Management*, *151*(August), 630–640.

Manggala Putra, R. P., Sutopo, S., & Pratama, H. B. (2019). Improved natural state simulation of Arjuno-Welirang Geothermal field, East Java, Indonesia. *Proceedings of 7th ITB International Geothermal Workshop (IIGW) 2018.*

Pasikki, R., Cita, F., & Hernawan, A. (2016). Application of experimental design (ED) in geothermal greenfield size assessment. *Proceedings: The 4th Indonesia International Geothermal Convention & Exhibition*, (July).

Pradhipta, Y. D., Sutopo, S., Pratama, H. B., & Adiprana, R. (2019). Natural state modeling of Mataloko Geothermal field, Flores Island, East Nusa Tenggara, Indonesia using TOUGH2 simulator. *Proceedings of 7th ITB International Geothermal Workshop (IIGW) 2018.*

Quinao, J. J. D., & Zarrouk, S. J. (2018). Geothermal resource assessment using Experimental Design and Response Surface Methods: The Ngatamariki geothermal field, New Zealand. *Journal of Renewable Energy*, *116*, 324–334.

Quinao, Jaime J., & Zarrouk, S. J. (2014). Applications of Experimental Design and Response Surface Method in Probabilistic Geothermal Resource Assessment – Preliminary Results. *Proceedinds, Thirty-Ninth Workshop on Geothermal Reservoir Engineering Standford University, Stanford, California, February 24-26,2014*, (1), 1–12.

Quinao, Jaime J, & Zarrouk, S. J. (2015). Probabilistic resource assessment using the Ngatamariki numerical model through experimental design and response surface methods (ED and RSM). *Proceedings New Zealand Geothermal Workshop, Taupo, New Zealand*, (November).

Quinao, Jaime Jose, & 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*, (April), 19–25.

Supijo, M. C., Wahyono, A. D., Lesmana, A., Harahap, A. H., & Berian, H. (2018). Updating Conceptual Model Using Numerical Modelling for Geothermal Green Field Prospect Area in Atadei , East Nusa Tenggara , Indonesia. *Proceedings of 6th Indonesia International Geothermal Convention & Exhibition (IIGCE) 2018, Jakarta.*