Experimental design and response surface method application in resources assessment: case study Karaha-Talaga bodas, West Java, Indonesia

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Abstract. The objective of this study is to build a numerical model which combine with experimental design method as a probabilistic approach to overcome the uncertainty parameters of reservoir so that can be obtained more valid assessment result. A Plackett-Burmann design method was used to minimize experimental simulation run into 12 experiments by investigating six uncertainty parameters with two degrees level. This process assesses the impact of evaluated parameters affecting resources and interacting between these parameters. This methodology have been successfully estimated the maximum resources with polynomial function covering the entire range of possible values of important reservoir parameters.

1. Introduction
The application of numerical simulation in green field has limitation as result of uncertainty parameters which appears due to unconstrained reservoir parameter and unidentified reservoir process. To account these problems, the probabilistic approach which fetch all of uncertainty subsurface parameters was used and was combined with numerical simulation to minimize the risk of error during assessment. Experimental design (ED) and Response Surface Method (RSM) which has a systematically process to assess the impact of evaluated parameters that affect the assessment and interaction between each parameter was applied in this study. The objective of this study is to build a numerical model which combine with experimental design method as a probabilistic approach to overcome the uncertainty parameters of reservoir so that can be obtained more valid assessment result.

The experimental design method was mainly applied in oil and gas industry to predict in improved production performance [5, 3, 4]. ED method was applied in the geothermal industry to assess resource field potency [12, 2] to evaluate the relationship between field production rate and decline rate [10], and to estimate the reservoir property [13].

A brief overview of experimental design theory is described in Figure 1. An ED was used to study the effect of three parameters (type of well, fluid injection, and well completion) to production. Because each parameter has two level, a low level (-1) and high level (+1), a factorial design with 2k number of experiment can be set up where k is the number parameters being studied. The combination of three parameters and two level requires 2k or 8 simulation runs, the factorial design is shown in Table 1.
When the simulation for all runs are done, the relationship between the production and the three parameters can be estimated by a response surface or proxy equation as follows where $X_0$ is the average response value. The polynomial equation shows the interaction between each parameter and the amount of interaction value between each parameter is indicated by the coefficient value of $X_1...X_7$.

$$
Y = X_0 + X_1A + X_2B + X_3C + X_4AB + X_5AC + X_6BC + X_7ABC 
$$

(11)

2. Karaha-Talaga Bodas Geothermal Field

Karaha Talaga Bodas geothermal field is located West Java, Indonesia, which contiguous with Mt. Galunggung. Karaha-Talaga Bodas field is categorized as partially vapor dominated system [8], where in southern area until center of the field has a steam dominated characterization while in the northern area tend to be water dominated. KTB geothermal field consists of two project areas, Karaha in the north area and Talaga Bodas in the south area. The temperature range of Karaha-Talaga Bodas reservoir varies from 250°C to 350°C, the highest reservoir temperature value based on the temperature measured in the deep brine reservoir zone, with the highest temperature area located in the south area, the temperature gradually decreased while heading to the north.

The Conceptual model is obtained from geology, geochemistry, geophysics study results, and well data. The Conceptual model describes several information such as heat source, natural fluid flow pattern, geological setting, caprock, upflow and outflow zone [7]. Figure 2 shows the existing conceptual model [1]. The Karaha-Talaga Bodas has a steam cap which underlain by deep brine reservoir. The steam cap extends from the south to the northern area where in the southern area has a thickest steam cap and
decrease while flowing toward north. Heat source location was estimated to be beneath Saat Crater and Talaga Bodas Lake. The upflow zone located in the southern area which is shown by the presence of multiple surface manifestations such as fumaroles; Talaga Bodas acid lake; several thermal springs; and the fluid characterization in the southern area which has high SO$_4$ and Cl concentration. The outflow zone of system located in the eastern area (Pamoyanan, Cicilap and Cipancing) [6].

Figure 2. Karaha-Talaga Bodas conceptual model [1]

3. Numerical Reservoir Model
The numerical model covers a total area 55 km$^2$, from 174000 to 179000 E and 9201000 to 9212000 N. The maximum elevation of surface model reaches 2087 m.a.s.l and the bottom of model was set to -2000 m below sea level. the grid block size varies from the smallest 250$\times$250 m to the biggest 500x500 m. The grid system is shown in Figure 3.

The model was constructed in single porosity with a rectangular grid and used 14 layers. The model was built using TOUGH2 software and the model was assumed pure water, therefore, EOS 1 was chosen for the equation of state. The total of number element or block is 11088. A 3D view of the model can be seen in Figure 4.

4. Natural State Model Validation
During the natural state process, the model was run until a steady state condition was reached. Model was validated using the pressure and temperature of seven wells, 3 wells from Talaga area (TLG1-1, TLG2-1, TLG3-1) and 4 wells from Karaha area (KRH1-1, KRH2-1, KRH4-1, KRH5-1). Figure 5 shows the comparison between the model and measured data. The figure also shows a prediction of deeper reservoir pressure and temperature profile. The pressure and temperature matching of all wells give reasonable match. The Model has been able to reproduce shallow (steam reservoir) and deep reservoir condition (brine reservoir).
Figure 3. Gridding system.

Figure 4. 3D model.
Figure 5. Pressure and temperature validation
5. Methodology
ED and RSM was used to study the effect of reservoir parameters modification to the assessment result and by this result can be generated Response Surface or proxy equation which describe the amount of electricity can be generated against reservoir parameters changed. ED and RSM workflow for resource assessment in this study are described in Figure 6. The workflow was started after a good validation result of the natural state model was achieved, then continue with the screening process of the ED parameters. Five investigated parameters were chosen based on the parameter that affect the power generation in the model and the parameter modification value which not give a significant change to the natural state condition. The minimum and maximum values of each parameters input which used in the simulation were tabulated in Table 2.

![Figure 6. Experimental design workflow.](image-url)
Table 2. Parameter ED input value.

| Parameter          | Low (-1)   | High (1)   |
|--------------------|------------|------------|
| Permeability (mD)  | -20% base  | +20% base  |
| Matrix Porosity    | -20% base  | +20% base  |
| Water Saturation   | 0.3        | 0.5        |
| Density (kg/m³)    | 2500       | 2700       |
| Feed Zone (m)      | -250       | -500       |

An ED Plackett-Burman design with 5 uncertain parameters (n = 5) at two levels (low [-1] and high [1]) was used in this study to identify the significant parameters which affect the amount of power generation for 30 years. A Plackett-Burman method could minimize the number of experiment into 12 which should be run for 2n or 32 runs by using full factorial design with not much different certainty result [11]. The twelve ED models design were generated using Minitab software, as shown in Table 3.

Table 3. Placket-Burman model design.

| Run | A   | B   | C   | D   | E   |
|-----|-----|-----|-----|-----|-----|
| 1   | -1  | -1  | -1  | -1  | -1  |
| 2   | -1  | -1  | 1   | 1   | 1   |
| 3   | 1   | -1  | -1  | -1  | 1   |
| 4   | -1  | -1  | -1  | 1   | 1   |
| 5   | 1   | 1   | -1  | 1   | 1   |
| 6   | -1  | 1   | -1  | -1  | -1  |
| 7   | 1   | 1   | -1  | 1   | -1  |
| 8   | 1   | -1  | 1   | 1   | -1  |
| 9   | -1  | 1   | 1   | 1   | -1  |
| 10  | 1   | 1   | 1   | -1  | 1   |
| 11  | -1  | 1   | 1   | -1  | 1   |
| 12  | 1   | -1  | 1   | -1  | -1  |

Where A is Permeability, B is Porosity, C is Water Saturation, D is Density and E is Feed Zone.

6. Electric Power Generation
The power generated simulation of 12 ED models were run for 30 years after made a change in the initial parameter value of validated natural state model with the new ED parameter value. 35 production wells were distributed in the centre of model as shown in Figure 7 where this area will be the development planning area.

All the production well was produced at well head pressure (WHP) 10 bar with PI 2.5E-12 m³ based on the maximum PI value from the production test result. The power capacity that can be generated from the model was calculated using the following equation. The equation describes the relationship between accumulated steam production and steam required during development phase [11].

\[
MW_e = \frac{\sum_{m=1}^{L} m \times \Delta t}{L \times SSC} \tag{2}
\]
where MWe is the power capacity, m is steam produced (kg/s), Δt is delta time at simulator (years), L is time project (years) and SSC is specific steam consumption (kg/s/MW).

The result of electric power generation for 30 years of steam production with 2.1 kg/s/MW of SSC is shown in Table 4. The minimum power capacity is 108 MW and the maximum is 135 MW. Analyze response of the power result in Table 4 which is conducted by using Minitab software generates a response surface or proxy model equation. This equation is used to determine a power capacity that can be generated from model as a function of the five uncertain parameters and coefficients of each uncertain parameters obtained from multiple regression process. The electric power generation calculation using proxy model in equation (3) was tabulated in Table 4 with deviation varies from 0.1 to 3.0.

\[
\text{MWe} = 121.0 + 6.3A - 1.7B + 4.7C + 0.8 D - 0.7E
\]  \hspace{1cm} (3)

From the analyze response result in Figure 8, permeability and water saturation are the two uncertain significant parameters which has a positive standardized effect. When these uncertain value increase from low level and high level, the response increase. The red line in Figure 8 describes all zero effects condition from the uncertain parameter.

![Figure 7. The development planning area](image)

The residual normal probability plot in Figure 9 which were generated from 12 ED Plackett-Burman design has already shown a normal distribution, so the MWe calculation with ED Plackett-Burmann which has a fewer run than full factorial design is enough to represent a valid result.
Table 4. The electric power generation of the model.

| Run | MWe  | MWe equation | Stdev |
|-----|------|--------------|-------|
| 1   | 113  | 112          | 1.0   |
| 2   | 121  | 121          | 0.2   |
| 3   | 125  | 123          | 1.5   |
| 4   | 111  | 112          | 0.6   |
| 5   | 121  | 121          | 0.1   |
| 6   | 107  | 108          | 0.8   |
| 7   | 121  | 122          | 1.0   |
| 8   | 134  | 135          | 1.1   |
| 9   | 123  | 119          | 3.0   |
| 10  | 131  | 129          | 1.7   |
| 11  | 113  | 116          | 2.3   |
| 12  | 132  | 134          | 1.1   |

Figure 8. The uncertain parameter effect normal plot.
Monte Carlo simulation was carried out based on proxy model in equation (3) with 50,000 iterations. The result in Figure 10 shows that based on numerical model, the Karaha-Talaga Bodas field can support power generation for 30 years with power capacity P10 of 116 MW, mean of 120 MW, and P90 of 125 MW. The standard deviation of Monte Carlo simulation result is small about 3.18 MW indicating the modification of uncertain parameters doesn’t give a significant effect to the power generation.

7. Conclusion

- The numerical model of Karaha-Talaga Bodas has successfully developed and validation results with the actual pressure temperature actual data show a good match.
- ED and RSM has successfully applied for electric power generation calculation in Karaha-Talaga Bodas numerical model.
- The Monte Carlo simulation based on ED Plackett-Burman for 30 years production generated power capacity P10 of 116 MW, mean of 120 MW, and P90 of 125 MW.
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