

## **Application Methods Experimental Design (*Plackett- Burman*) in Uncertainty Parameters Reservoir Vapour Dominated**

Riswan H, R.

The Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung (ITB) Indonesia

riswan@alumni.itb.ac.id

**Keywords:** Uncertainty, experimental design, alternative conceptual models

### **ABSTRACT**

At the beginning development of the field to interpret the geothermal system is realized one or two conceptual models. It's often the case at this time there is a surprise when addition of the data hence it will be a new interpretation of the geothermal system. It will impact in a revised planning of the field development due changes in the initial estimate geothermal reserve (reservoir assessments). The objective of this paper is to change the way of looking on the geothermal company that one of the factors that should be considered more seriously in the early development of the field is uncertainty reservoir parameter.

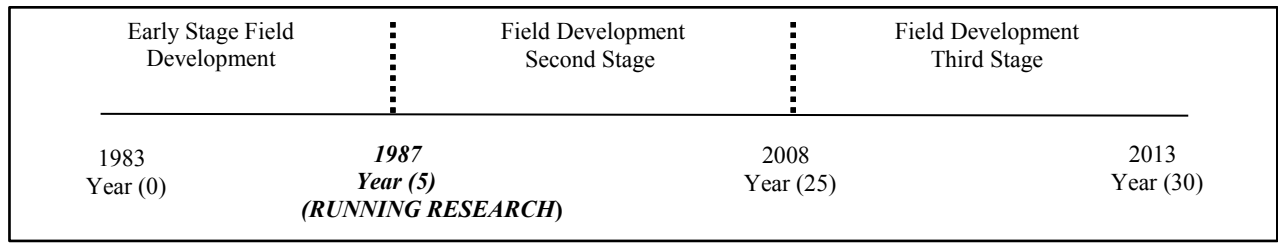
The uncertainty reservoir parameters will be influential in building a reservoir simulation model. In order to optimize the uncertainty parameters data of reservoir can be performed using method experimental design. The research of this paper aims to estimate the actual condition reservoir at the start of the development that have limited data, by establish some alternative conceptual models based on parameters uncertainty reservoir. Thus, there is no surprise even though an addition of new data.

### **1. INTRODUCTION**

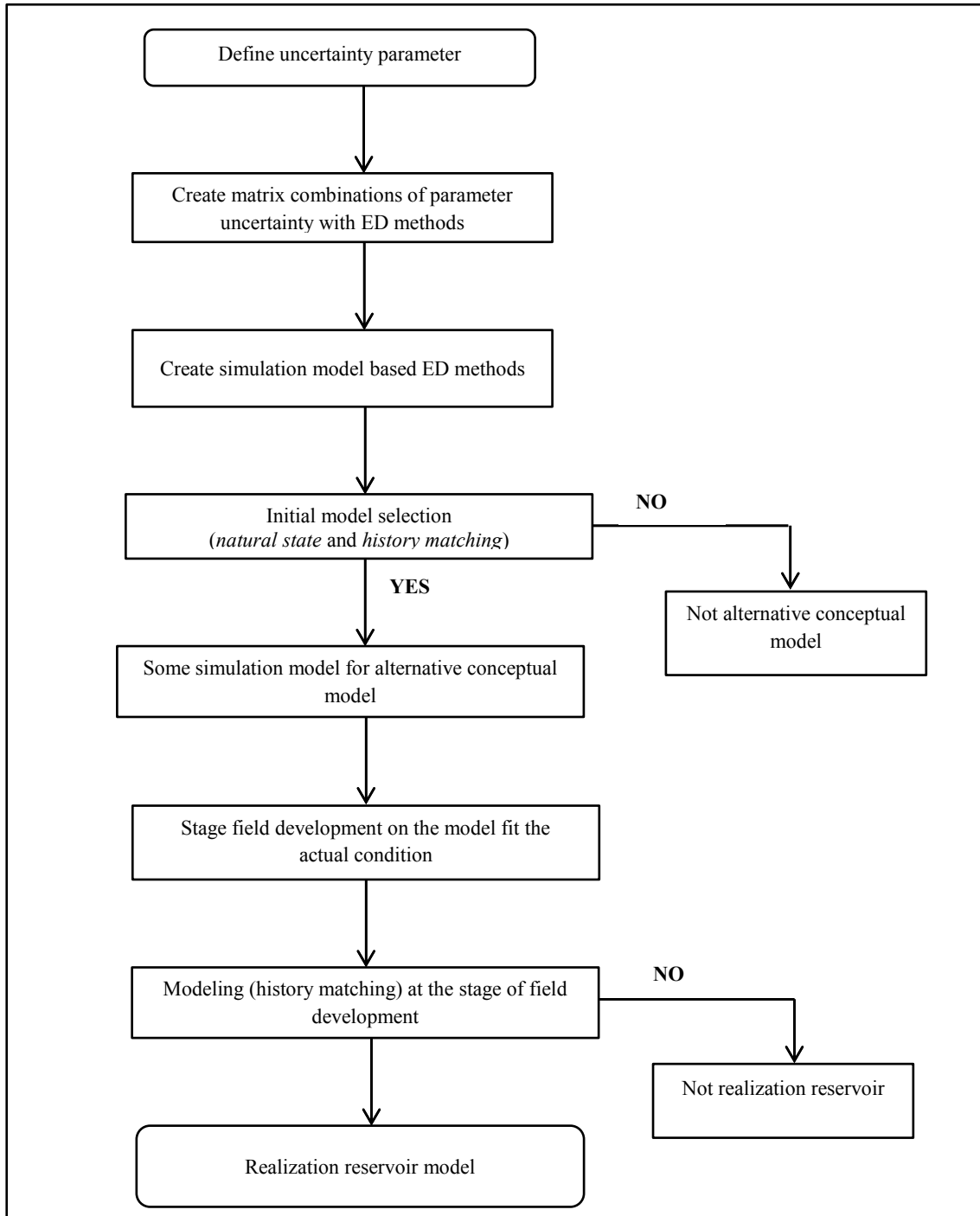
Nowadays, In geothermal company to describing a geothermal system using only one or two sketches of the conceptual model. Furthermore, running the various scenarios in the field development plan based on a conceptual model that has been created and quantify the investment value of each scenario. Along with the additional data it will produce a new interpretation of a geothermal system, the conceptual model needs to be updated. It is should revise the scenario of development of the field because of changes in the initial estimates value of reserves (heat stored) and automatically have to recalculate the company's investment portfolio. Then, this is used as the rationale to research that aims to change the way in developing a geothermal field that things need to be considered more serious is the uncertainty of reservoir parameters.

Uncertainty reservoir parameters will be influential in building a simulation model. In terms to optimize the parameters reservoir uncertainties can be done using a probabilistic distribution function. Distribution probabilistic process developed using experimental design (ED) to determine the parameters of uncertainty associated with the reservoir condition. Application of this method is used to run all combinations of input parameter values. In the petroleum industry, ED method has been used to reduce amount reservoir simulation run of parameter studied.

In this study, the research will be done on one of geothermal field vapour dominated which has been operating for 30 years. In early stages field development for the years 1983 - 1987 has been carried out the drilling of five wells. Then the researchers conducted experiments in the early stage of development to determine the actual condition of reservoir in the future by applying ED to build several simulation models based on parameters reservoir uncertainties. Determination uncertainty reservoir parameters based on a review study of geoscience and measurement initial well data. The model has been established will be choosing a model which is natural state and history matching to define the actual field conditions. Then, some of models that have been selected will be used as an alternative conceptual model. Some models have done modeling history matching will develop in accordance with the actual conditions and there is a model that follows trend values of pressures and temperatures approaching the real conditions, accordingly we obtain a model to describe the realization reservoir geothermal field vapour dominated truth.



**Figure 1: Work Time Sequence Flow Chart**



**Figure 2: Flow Chart of Research Methodology**

## 2. EXPERIMENTAL DESIGN FOR RESERVOIR SIMULATION

Experimental design is a scientific approach that allows researchers to comprehend the process and to determine how an input affects the response, Atmoko (2011). In this case the uncertainty of reservoir parameters as input factors and the results of reservoir simulation model as a response is generated. In general, it is assumed that a process that involves response  $y$  which depends on variables  $\xi_1, \xi_2, \dots, \xi_k$ . That relationship is expressed as follows:

$$y = f(\xi_1, \xi_2, \xi_3, \dots, \xi_k) + e$$

Where  $f$ ,  $e$  response function is actually unknown, error factor which represents another source of variability that are not calculated in  $f$ , respectively. Variables  $\xi_1, \xi_2, \dots, \xi_k$  is natural variables as expressed in a natural measurement units. In a study of ED, natural variables transformed into a variable coded  $x_1, x_2, \dots, x_k$  where these variables dimensionless with a mean of (0) and distribution [-, +]. Value (-) and (+) are called level and represent respectively the minimum and maximum variable. Can be re-formulated as:

$$y = f(\xi_1, \xi_2, \xi_3, \dots, \xi_k) + e$$

The ED method has been used in the oil and gas industry, which has been applied to the geothermal industry that aims to develop the field an early stage by using probabilistic prediction of reservoir, Kabir et al (2004). The ED method has been used in various applications such as reservoir engineering predictions of reservoir behavior, modeling uncertainty, sensitivity studies, history matching and optimization of development. The ED method can apply the idea to do a running simulation minimum and gathering information optimum as well from the simulation results. There are several methods of experimental design that is often used within the industry such as; Plackett-Burman, Taguchi and Box-Behnken, Donaldson et al (2004). Each of the experimental design method has advantages and disadvantages, Ariadji et al (2012). In this study used plackett-Burman design method.

Plackett-Burman design suitable for studying a factor of  $k = (N-1) / (L-1)$ , where  $(L)$  is the number of levels and  $(k)$  is a number of factors. Advantages of this design are all main effects are estimated with the same precision. In the experimental design factors that will be included generally coded (-), (0), (+) for the three levels of the minimum, midpoint, and maximum, whereas in this study will be used two levels, namely the minimum and maximum will coded (-) and (+). Software used in ED is to use Minitab software, Ariadji et al (2012).

## 3. UNCERTAINTY RESERVOIR PARAMETERS

Define of parameters uncertainties based on a review study geoscience and measurement of the initial well data. Uncertainty of reservoir parameters, among others: permeability, porosity, density of rocks, water saturation, temperature, thickness and reservoir area.

### 3.1 Permeability

The value of permeability rock is not same in all directions (anisotropy). In general, at the direction of lateral permeability greater than the permeability in the vertical direction. Permeability included into the parameter uncertainty in the range of 50-200 mD in the lateral direction ( $x, y$ ), and 10-50 mD in the vertical direction ( $z$ ).

### 3.2 Porosity

Reservoir rock porosity in this field have not been obtained raw data or data from the original measurement, subsequently to determine the porosity of the reservoir is done by analogy approach, namely reference to the porosity of geothermal field its around. Two-phase system in the northeast field vapour dominated, and the reservoir has a total porosity of 7% (Sudarman et al, 1986), while the field with the same system that the vapour dominated are in the north has a porosity reservoir of 5-9% (Schlumberger, 1993). Based approach analogy refers to the porosity value, then the value of porosity field vapour dominated reservoir of about 8% (0.08). Because at a certain depth based on lithological rock penetrated by drilling wells on the reservoir porosity value could reach 27% (0.27), accordingly the porosity belong to the uncertainty parameter value range 0.08 to 0.27.

### 3.3 Rock Density

In general, the rock formations in the geothermal reservoir is volcanic igneous rock. Some examples igneous volcanic contained of reservoir vapour dominated are andesite and basaltic. Andesite has a density of about 2350 - 2500 kg / m<sup>3</sup>, while the basaltic rock has a density of about 2500 to 2700 kg / m<sup>3</sup>. In the reservoir vapour dominated, rock density values will always be different at any depth based on the type of rock in each formation lithology. Based on the value of the density of rocks belonging to the uncertainty parameter value range 2350 - 2700 kg / m<sup>3</sup>. ([future20.wordpress.com](http://future20.wordpress.com))

### 3.4 Saturation Water

The average value saturation water from five production wells has a percentage of 20.5%. Calculation of percentage water saturation was performed by Grant (1979), that the average percentage of water saturation field vapour dominated at the beginning of exploitation is 35%. A decline in the value of water saturation about  $\pm 0.72\%$  annually. Based on this, the saturation of water into the parameter uncertainty with the percentage range of 25% - 35%.

### 3.5 Reservoir Temperature

Reservoir temperature can be determined by comparing the temperature measurement wellbore (downhole) and mineral alteration. The presence of epidote minerals can be used as a reference to determine the reservoir temperature range. Studies on the well DU-XX and

(YY), at which time drilling obtained mineral epidote have temperature are 245 °C and 200 °C, respectively. Based on the measurements wellbore and the presence of mineral epidote, the reservoir temperature ranges from 220-260 °C.

**3.6 Thickness**

Geophysical using Schlumberger array and geomagnetic methods applied to the field vapour dominated, where both of these methods has found anomalous low resistivity zones which show potential geothermal reservoirs. Using a resistivity traverses, estimated the value of the resistivity structures associated with the presence of clay zone (impermeable) and the reservoir zone (feedzone) in the geothermal field vapour dominated, Sudarman et al (1983). In 1980, an additional 27 resistivity soundings with a distance of up to  $AB / 2 = 2000$  m. These data, simultan with reconnaissance surveys that enable more detailed measurements on the pseudo resistivity map. Based on the interpretation of the data on geophysical methods with Schlumberger array and geomagnetic methods as a whole, it can be estimated thickness of the reservoir probable 1000 - 2000 m.

Both of thickness and proven area reservoir based on the existence initial wells on the field vapour dominated. Based on temperature profile on the fifth wells have been drilled an estimated average convection zone is located at an elevation of 1100 - 600 masl. The convection zone is interpreted as a productive zone (feedzone) the vapour dominated reservoir. Based on the results of the inversion method CSAMT 2-D and measurement of well data, the thickness of the reservoir is inserted into the parameter uncertainty in the range of 500-2000 m.

**3.7 Area**

Geophysical method based on the measurement of residual Bouguer anomaly and magnetic, to conclude reservoir probable area can reach 21 km<sup>2</sup>, Sudarman (1983). One should note that geophysical methods in geothermal exploration to determine the subsurface structure of the zone where the reservoir can not be fully used as a reference. This method must be supported by geological and geochemical studies such as the presence of surface manifestations and upflow zones can be used as a reference to determine probable reservoir area.

Based on temperature profile, an estimated five wells have been drilled to penetrate the high-temperature reservoir zones. Results of this study are used as a reference to determine extent of reservoir proven at 14 km<sup>2</sup>, which is further supported by the measurement of the DC-Schlumberger soundings with the same reservoir area, Hochstein (1975). Based on inversion method CSAMT 3-D and existing well production, then reservoir area belonging of parameter uncertainty in the range of 14-21 km<sup>2</sup>.

**4. EXPERIMENTAL DESIGN: PLACKETT-BURMAN**

Uncertainty reservoir parameters that have been specified, then performed the experimental design (ED) on all factors. The ED method is aimed to reduce the number of reservoir simulation run, therefore the time needed more quickly and effectively without having to conduct a sensitivity analysis to construct a lot of models in all parameters of uncertainty. In this study the chosen method ED of Plackett-Burman 20 run (PB-20) in performing design analysis. The use of 20 run due to obtain some reservoir simulation model that can approximate the actual condition.

**Table 1: Eight (8) Parameters Reservoir Uncertainty**

No.	Factor	Min. Value	Max. Value
		(-)	(+)
1	Sat. Water	25	35
	(%)		
2	Permeability (X,Y) (k)	50	200
	(mD)		
3	Permeability (Z) (k)	10	50
	(mD)		
4	Porosity (φ)	8	27
	(%)		
5	Rock Dens. (ρ)	2350	2700
	(kg/m <sup>3</sup> )		
6	Res. Temp.	220	260
	°C		
7	Depth (h)	500	2000
	(m)		
8	Area (A)	14	21
	(km <sup>2</sup> )		

In term to simplify the job, then use Minitab software on the ED Method. Plackett-Burman matrix obtained is randomization of input parameters analyzed. Once the matrix table is formed, then made a run simulations based on the matrix table.

**Table 2: Details of the Symbols on the Uncertainty of Reservoir Parameters**

Symbol	Factor
A	Saturation Water
B	Permeability (X,Y) (k)
C	Permeability (Z) (k)
D	Porosity ( $\phi$ )
E	Rock Density ( $\rho$ )
F	Res. Temp. (T)
G	Depth Reservoir (h)
H	Area (A)

**Table 3: Design Matrix Combinations Provided by PB-20 with Two Levels for All Factors**

RUN	A	B	C	D	E	F	G	H
Sim. 01	+	+	+	+	-	-	+	+
Sim. 02	+	-	+	+	-	-	-	-
Sim. 03	+	-	+	-	+	+	+	+
Sim. 04	-	+	-	+	-	+	+	+
Sim. 05	-	+	+	-	+	+	-	-
Sim. 06	-	-	+	-	+	-	+	+
Sim. 07	+	+	+	-	-	+	+	-
Sim. 08	+	+	-	-	-	-	+	-
Sim. 09	-	+	-	+	+	+	+	-
Sim. 10	-	-	+	+	-	+	+	-
Sim. 11	-	+	+	-	-	-	-	+
Sim. 12	-	-	-	-	+	-	+	-
Sim. 13	+	-	-	+	+	-	+	+
Sim. 14	+	+	-	+	+	-	-	-
Sim. 15	+	-	+	+	+	+	-	-
Sim. 16	-	-	-	+	-	+	-	+
Sim. 17	+	-	-	-	-	+	-	+
Sim. 18	-	-	-	-	-	-	-	-
Sim. 19	-	+	+	+	+	-	-	+
Sim. 20	+	+	-	-	+	+	-	+

**5. RESULT AND ANALYSIS**

Based on results of a simulation model that has been built, furthermore to ensure that the model has been constructed to represent the actual systems in the field. In this case, modeling natural conditions and historical production data (history matching). Natural state stage aims to determine the initial reservoir conditions before being produced, while the stage of history matching aims to determine whether the model that has been made already represent actual field conditions after the production data.

Start of this research from the years 1983 - 1987, which in that period is the early stage of field development. In the early stages, the field vapour dominated only producing five wells (DU-AK, DU-AN, DU-AQ, DU-AR, and DU-AV).

### 5.1 Natural State Model

The simulation model is considered to have represent natural state conditions if the relative do not change in pressure and temperature within a very long time. On modeling natural state, the result of constant analysis time step and end time is set on the state of infinite because the purpose of modeling is to create a steady state condition that created by analysis TOUGH2. In this model it is assumed natural state conditions have been reached if the delta time step simulation has reached millions of years.

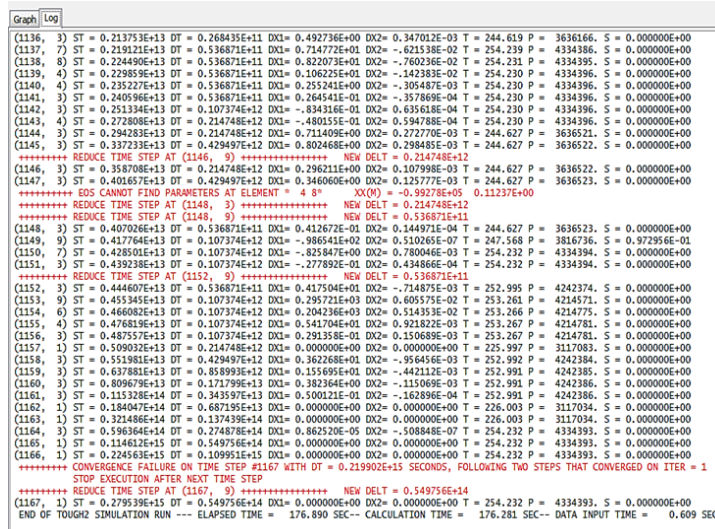


Figure 3: Log Results on Simulation Model (01) When the Analysis TOUGH2

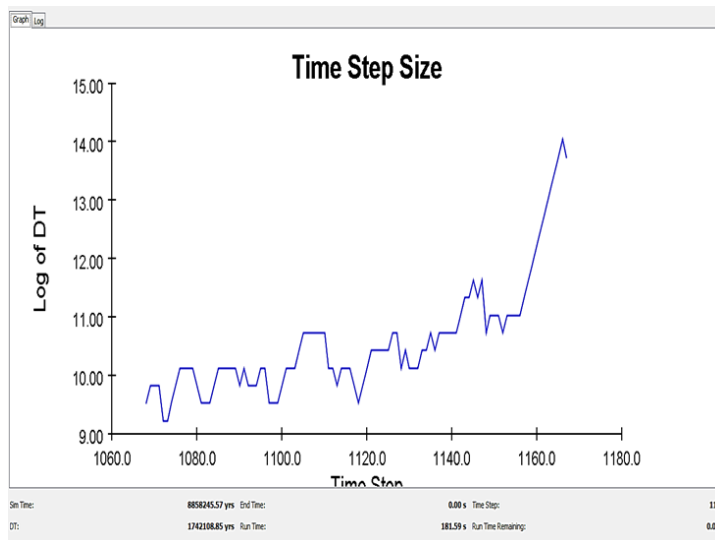


Figure 4: Graphic Analysis Simulation Model (01) When Natural State Condition has Reached

Furthermore, after running natural state is to perform matching between the pressure and temperature on the model of the value of the temperature and pressure observation data. If there has been a good match between pressure and temperature of the model results against the results pressure and temperature of the observation model, it can be said to have reached the natural conditions (natural state).

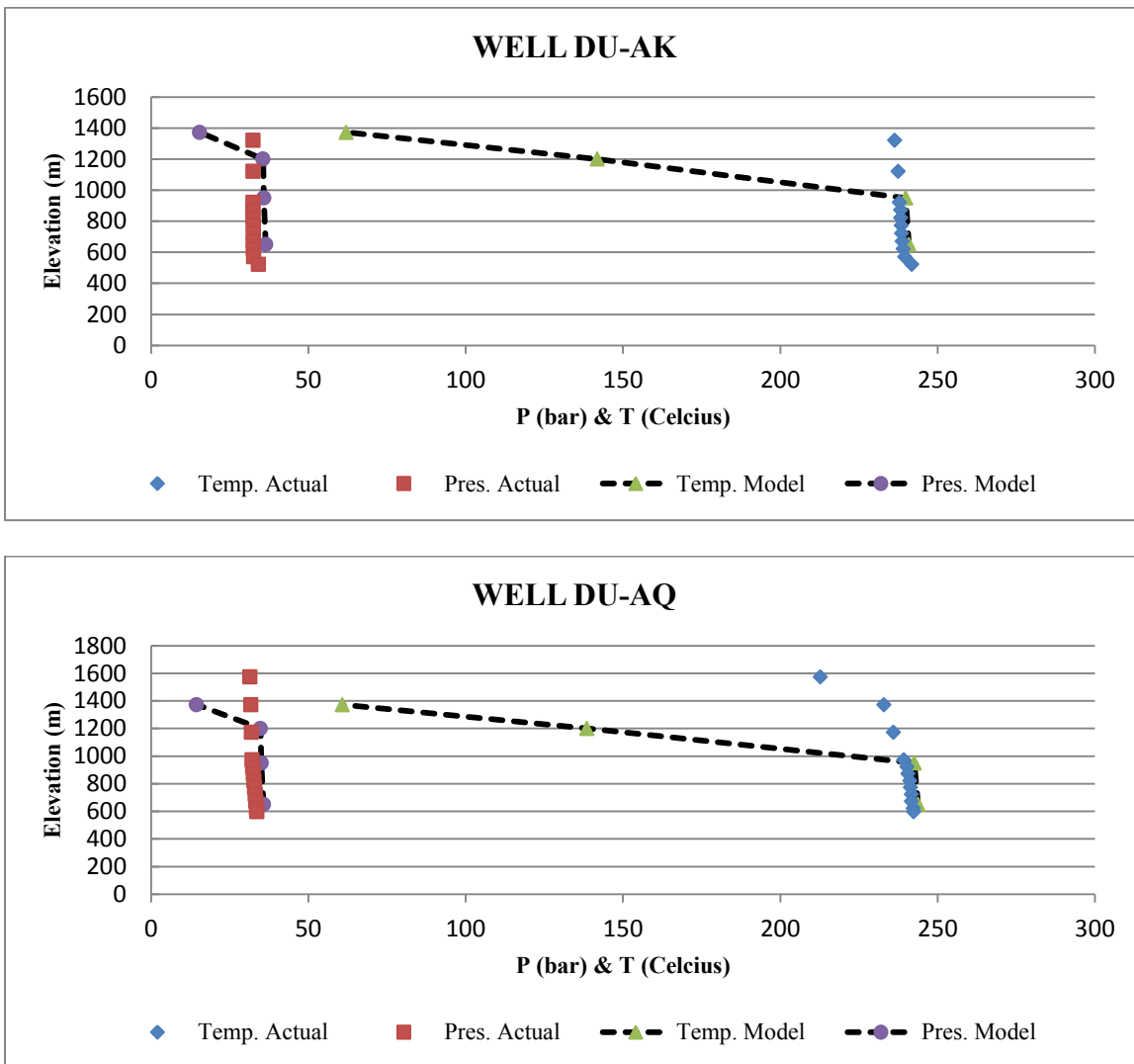


Figure 5: Natural State Matching between Model Simulation (01) and Observation Data

### 5.2 History Matching

History matching stages is done after the simulation model has reached natural state condition. The purpose of history matching is to align model response with field measurement data when the well is in a state of being produced at a certain time. Initial pressure and temperature conditions used were the last condition derived from natural state stage, and then put the five wells that have been produced in the model. Well data has been input into the model, performed TOUGH2 running for five (5) years in accordance with the conditions of the early development of the field. Furthermore, the alignment between pressure and temperature on the model of the pressure and temperature obtained from the results of field measurements.

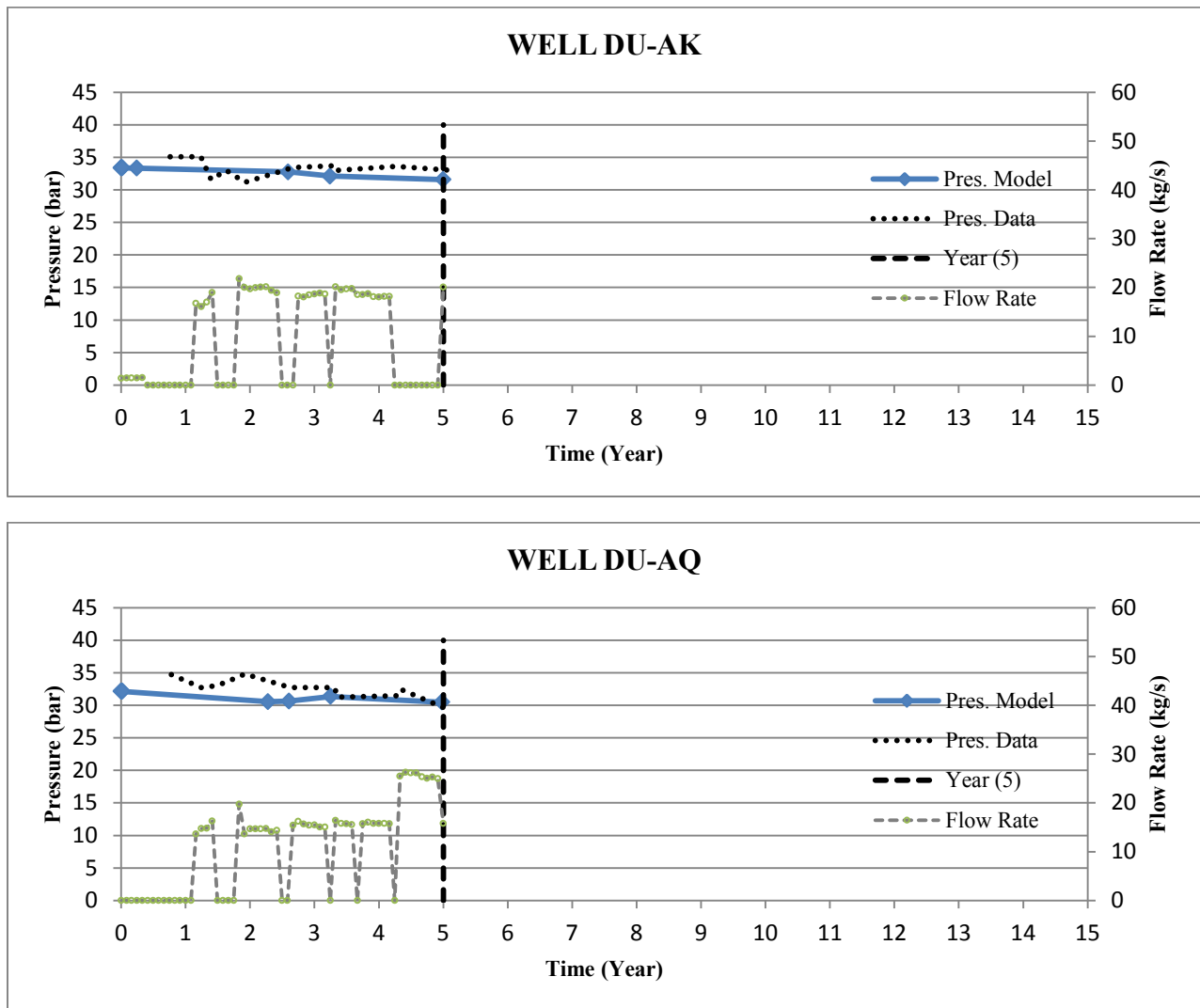


Figure 6: Production History Matching between Model Simulation (01) and Observation Data

### 5.3 Summary All Models

Results of running twenty (20) reservoir simulation model that has been built based on a predetermined parameter uncertainty, and then selection of the entire model. At this stage of modeling the natural conditions (natural state) obtained eleven (11) models have reached the condition. Moreover, the model of production history data (history matching), from 11 models obtained ten (10) models that achieve these conditions. Results of the 10 simulation model that has achieved the condition of history matching, it can be justified that 10 model is an alternative conceptual model geothermal field vapour dominated.

**Table 4: Summary 20 Reservoir Simulation Model in the Model Selection**

No.	Model Simulation	Selection Model	
		Natural State	History Matching
1	Model 1	V	V
2	Model 2	-	-
3	Model 3	V	V
4	Model 4	V	V
5	Model 5	-	-
6	Model 6	V	V
7	Model 7	V	V
8	Model 8	V	-
9	Model 9	V	V
10	Model 10	V	V
11	Model 11	-	-
12	Model 12	V	V
13	Model 13	V	V
14	Model 14	-	-
15	Model 15	-	-
16	Model 16	-	-
17	Model 17	-	-
18	Model 18	-	-
19	Model 19	-	-
20	Model 20	V	V

**Table 5: Summary of Number Reservoir Simulation Model**

No	Modelling	Number of Model
1	Natural State	11
2	History Matching	10

#### 5.4 Field Development Stages

In that case as evidence, to determine the condition actual reservoir of the field vapour dominated, then the stage development from 5th year (1987) until the 30th year (2013). From Total 10 simulation model that has been gained and then re-running TOUGH2 for 30 years. Stages of development made in the model are the actual conditions that existed at the development field vapour dominated. During the development stage of the field from the year 1987 - 2013 has done as much as  $\pm 70$  wells drilling. However, from total wells drilled only about 43 wells that produced and seven (7) wells were converted to injection wells.

Results from 10 simulation model that has been done re-running TOUGH2 analysis obtained four (4) models that achieve the simulation time of 30 years. Meanwhile, the six (6) other models that do not reach the simulation time. Then from four models, re-run process modeling history matching on five wells and obtained only two (2) model (models 01 and 04 models) that have good matching.

Furthermore, these two models can be regarded as a model to represent the condition of vapour dominated geothermal field as a whole and can be used as a basic model to plan the next stage of field development.

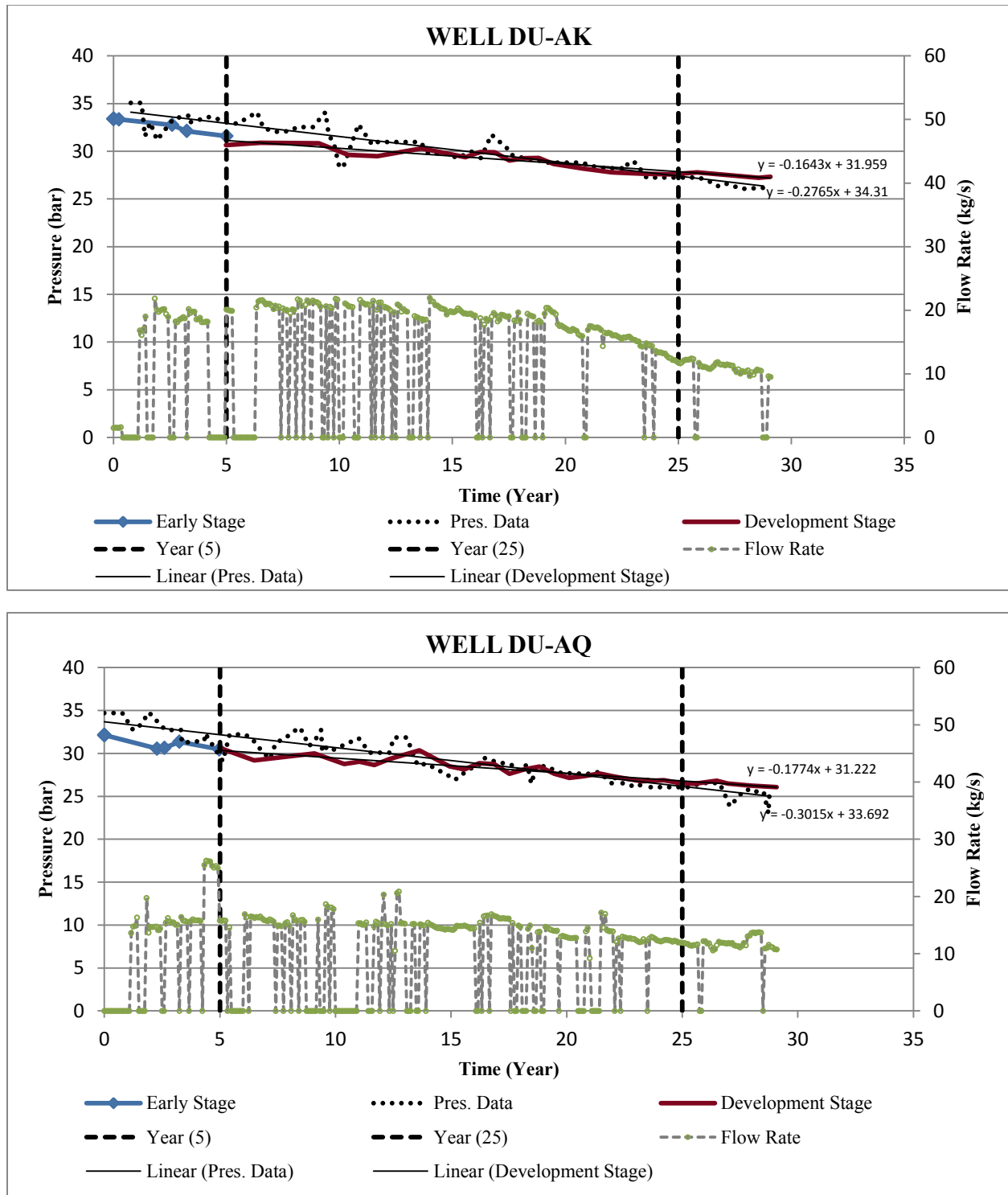


Figure 7: Production History Matching Development Stage (30 years) between Model Simulation (01) and Observation Data

### 6.5 Comparison Result of Simulation Model Against Actual Condition

Two simulation models that have reflected the actual situation, then a comparison (in the form of a matrix table) between simulation model and actual condition of the field over a period of 30 years to determine the performance reservoir on the value of pressure and

temperature at a certain period. Both of pressure and temperature decline will be used linear regression analysis to determine the equation or the function of each decline curve in individual well. At each function will be known the gradient value.

**Table 6: Comparison Pressure Temperature Simulation Model (01 and 04) and the Actual Condition of the Field**

Data	Year	Model Sim. 01					Model Sim. 04					Field Data				
		DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV
Pressure (bar)	0	33.4	32.8	32.1	32.5	36.2	33.4	32.8	32.1	32.5	36.2	35.1	34.7	34.7	34.4	34.7
	5	30.6	28.7	30.6	29.5	35.3	32.1	30.4	30.0	30.5	35.7	33.2	29.8	29.2	32.9	32.1
	10	29.6	29.0	28.7	28.9	32.1	29.6	27.7	28.6	28.6	30.1	28.3	29.1	29.8	30.6	30.2
	15	29.4	28.3	28.1	28.4	29.5	29.5	27.9	28.1	28.1	29.4	29.6	23.0	27.2	28.7	27.2
	20	28.2	26.9	27.1	26.8	27.1	28.7	26.8	27.3	26.7	26.8	28.8	21.5	27.7	27.1	27.6
	25	27.8	26.3	26.4	26.4	25.2	27.5	26.4	26.5	26.3	25.5	27.3	20.6	26.3	27.3	25.9
	30	27.3	25.8	26.0	25.5	23.2	26.8	25.3	25.6	25.1	23.3	26.1	18.6	25.7	24.3	24.2

Data	Year	Model Sim. 01					Model Sim. 04					Field Data				
		DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV
Temp. (°C)	0	239.8	238.8	237.7	238.4	244.5	239.8	238.8	237.7	238.4	244.5	242.7	242.1	242.1	241.6	242.1
	5	235.0	231.5	235.3	232.1	240.2	238.1	234.6	233.7	234.8	243.5	239.4	233.5	232.2	239.1	238.1
	10	233.1	231.6	231.7	231.2	236.6	233.6	230.4	231.6	232.1	233.8	230.6	232.2	234.4	235	233.7
	15	232.7	230.1	230.5	230.7	232.4	232.9	229.8	230.3	229.7	232.1	232.6	222.3	228.4	231.4	231.2
	20	230.8	227.8	228.4	227.7	228.4	231.2	227.8	228.7	227.8	228.2	231.6	216.2	229.5	228.3	229.4
	25	229.5	227.2	227.1	227.2	226.9	229.4	227.1	227.4	226.9	226.8	228.6	213.8	226.7	227.6	226.7
	30	228.7	225.5	226.2	225.1	226.7	228.1	224.6	225.2	224.2	226.4	226.7	210.3	225.6	224.3	225.8

Factor	Model Sim. 01					Model Sim. 04					Field Data				
	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV	DU-AK	DU-AN	DU-AQ	DU-AR	DU-AV
Pressure Decline /Year (bar)	0.16	0.17	0.18	0.19	0.44	0.21	0.17	0.18	0.20	0.40	0.28	0.46	0.30	0.30	0.30
Temp. Decline /Year (°C)	0.31	0.34	0.35	0.35	0.64	0.39	0.34	0.35	0.41	0.55	0.51	0.97	0.57	0.56	0.57

## 6. Conclusions and Recommendations

### 6.1 Conclusions

1. Based on 20 reservoir simulation model that has been built based on uncertainty reservoir parameters using ED method, then the natural state modeling and history matching on each model, obtained 11 simulation models that reach state natural conditions and obtained 10 models at the stage of history matching.
2. On 10 models derived from modeling history matching the early stages of development (1983-1987) can be used as an alternative conceptual model of the geothermal field vapour dominated.
3. On 10 models that have been obtained in the history matching process, then performed development stage of the simulation model in accordance with the actual conditions of the field vapour dominated, then re-run modeling history matching at development stage, obtained two (2) models that have good matching.
4. Two simulation models (models 01 and 04) were obtained from the modeling history matching at stage field development can represent the actual condition of the field as a whole and can be used as a reference initial model to determine vapour dominated field development planning of the next stage.

## 6.2 Recommendations

1. In the application method of experimental designs (Plackett-Burman) has been done in this study, can be used the number of permutations or the number of simulation models that more above ( $> PB = 20$ ) to obtain alternative conceptual model that may be more in determining the truth condition of the field .
2. In the case study the green field will be developed with limited data, the application of this method can estimate the actual condition of the field by create some alternative conceptual model based on parameter uncertainty reservoir where each model will be made some similar scenario then calculated the value of the investment in each scenario. Furthermore, developers will choose the best scenario from the scenarios that have been planned. It aims when there is the addition of new data can avoid any surprises to anticipate in the early stages of development.

## ACKNOWLEDGMENTS

The authors would like to thank Mr. Zuher Syihab that has guided me in this study. The authors would also like to thank Ilham Pane and Dede Irama for valuable discussions on process modeling and Nurita Putri for invaluable assistance with TOUGH2.

## REFERENCES

- Abidin, Z., et al.: Geothermal Reservoir Characterizaion for Steam Filed Management in Kamojang Geothermal Field-West Java, BATAN, Bandung, (2009).
- Browne, P.R.L., and Utami, Pri.: Subsurface Hydrothermal Alteration in the Kamojang Geothermal Field, University of Auckland, New Zealand, (1999).
- Fisher, S.R.: The Design of Experiments, Hafner Publishing Company, New York, United States, (1935).
- Hochstein, M.P.: The resistivity of porous partly-saturated media, *Proceedings*, New Zealand Geothermal Workshop, University of Auckland, Geothermal Institute, New Zealand, (1980), 101 – 104.
- Oghena, A.: Quantification of Uncertainties Associated with Reservoir Performance Simulation, Texas Tech. University, United States, (2007).
- Kabir, C.S., et al.: Developing New Fields Using Probabilistic Reservoir Forecasting, SPE Reservoir Evaluation and Engineering, Texas, United States, (2004).
- Kamah, Y., et al.: Mass Variation in Outcome to High Production Activity in Kamojang Geothermal Field, Indonesia: A reservoir Monitoring with Relative and Absolute Gravimetry, Jakarta, Indonesia, (2011).
- Pruess, K.: Modelling of Geothermal Reservoirs: Fundamental Process Computer Simulation and Field Applications, *Proceedings 10th*, New Zealand Geothermal Workshop, New Zealand, (1988).
- Quinao, J. J., and Zarrouk, S. J.: Applications of Experimental Design and Response Surface Method in Probabilistic Geothermal Resource Assessment – Preliminary Results, *Proceedings*, Thirty-Ninth Workshop on Geothermal Reservoir Engineering, California, (2014).
- Rahardianto, A.: *Evaluasi Injeksi terhadap Lapangan Panas Bumi Dominasi Uap XX Berdasarkan Model Dinamik*, Institut Teknologi Bandung, Bandung, (2013).