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# Decline Curve Analysis for Production Forecast and Optimization of Liquid-Dominated Geothermal Reservoir

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**Abstract.** Power projects in the geothermal field has a long span of about 30 years. The power supply should be maintained at a certain value across a range of time. A geothermal field, however, has the characteristics of natural production decline with time. In a geothermal field, development of decline curve model of steam production is important for forecasting production decline in the future. This study was developed using decline curve by production data along 3 years liquid-dominated geothermal reservoir in Ulubelu field. Decline curve in geothermal field based on decline curve in petroleum industry. The decline curve was correlated by reservoir management in geothermal. The purposes of this study to get best match model decline curve and forecasting production in the future. Based on decline curve analysis by production data in Ulubelu field, the result model decline curve is exponential model. From the model, we can get the value of decline rate in the field is 9.4 %/year. Then, the formula of forecasting steam flow used exponent decline to forecast in the future. By using separated system cycle in Ulubelu field, the minimal steam flowrate towards turbine was 502018.4 ton/month. Based on formula of forecasting production and minimal steam flowrate, we can get the time make up wells to maintain steam supply for stability in generator power capacity.

Keywords: decline production, curve, liquid- dominated

## 1. Introduction

Indonesia is a country with a plenty resource of geothermal energy which is also as the biggest one in the world. Geothermal energy potential resources which is reach the value of 28,910 MW (Indonesia Energy Outlook, 2014). The mostly reservoir type in the world is water dominated. Especially in Indonesia, water dominated system is majority in geothermal system about 80% (Saptadji, 2015).

### 1.1 Production Management

A geothermal field that are developing and start to production, management of production and injection operation is important thing to be done. This is a multidisciplinary tasks involving production monitoring, geochemistry, reservoir engineer, and simulation to get cumulative field data in production and injection that measured in subsurface and surface. One of tasks is to maintain sufficient supply of steam to electrical generator.



Electrical power project in geothermal field has time range about 30 years. All this information must be brought together into a coherent model that can be used to predict future production, injection capacity, and to identify any areas where remedial action must be planned in order to maintain the production plant at full capacity. These actions range from scheduling from simple well cleanout to remove calcite scaling to moving the injection well field to avoid returns of cool fluids between injection and production wells.

Some data will be available frequently: wellhead pressure (WHP), valve settings, separated-steam and brine flows, total flow (mass and enthalpy) from separator stations, injection well flows and temperatures, and so on, together with reservoir monitoring data that mainly comprise pressures in observation wells. Other data may be available only intermittently, such as mass flow rate, enthalpy, and chemistry of individual wells.

In production wells, if the production WHP and enthalpy remain constant, the mass flow changes in response to changes in reservoir pressure. This is cause of production decline, initially rapid and then flattening out as time goes on. A change in trend indicates some change in the well that may require further investigation. The model production decline can identify some problem in the field with look the trends. A detail of the model provides a better predictor of performance and give explicit ability to model effect of particular changes, such as deposition or cooling of one feed zone.

### *1.2 Decline Curve*

Production model is obtained from decline curve analysis. Initially decline curve analysis is used in petroleum industry and then used in geothermal field because the same principal. The decline model discusses a model or trend-fitting of well performance in order to establish a simple model to project future performance. Such trend analysis provide the best projections for short term extrapolations, provide that condition do not change. They are not reliable as models of long term reservoir performance or capacity because large-scale reservoir processes are not reflected in the fitting process. In geothermal field, there are two kind of decline curve, are exponential model and harmonic decline. Exponential model is a form decline where the flow decreases by constant fraction or percentage per year. The other forms, harmonic decline plot rate versus time. The plot used logarithmic scale in time and rate production used linear scale generate linear plot.

In this paper, the decline model just used surface production data. The production data used steam flow rate towards turbine versus time along three years in Ulubelu field. For optimizing the productions, developing model could easier to check condition of production in the current and the future. The example, the big trouble in Geyser field is declining flow rate about 50% in 8 and 12 years (Ripperda, 1987). The installed generation capacity in this field peaked at about 2000 MWe in 1989. But present generation capacity of about 850 MWe will have declined to about 700 MWe over the next two decades (Sanyal and Eneedy, 2012). The other problem happened in water dominated geothermal field (Dieng Field). In Dieng geothermal Field, the geothermal plant contain a lot of Silica in fluids, making scales. As a consequence, at present, it only generates 40MW of electricity compared to the expected 60MW output (ECFA, 2006). One of the ways to identify the problem is decline curve analysis.

## **2. Methodology**

Based on decline curve analysis, develop the model is used field production data in plot to time. We required production data especially fluids flow rate versus time. In this case, the production data is taken along 3 years production versus time. The result of graphic then used to determine model of decline curve.

Based on literature study, decline curve in geothermal field is basically from decline curve petroleum industry. The most using model in geothermal field are harmonic model and exponential model depend to decline rate. Then, understanding about production management principal especially in liquid-dominated reservoir geothermal field.

Selection of the model is making match actual data by plotting the model. Then, comparing of both model that matching with actual data. The best matching model with actual data is chosen. There are two way to determine best model, the first one is qualitative and the second is quantitative way. The qualitative way is to find the best model by look the most linear graphic. But the quantitative way is to

find the best model by using R-square value. The bigger R-square value is the best model. So that, both way is consider to determine the best model decline curve in liquid-dominated geothermal.

The best model is used to analysis production problems and forecasting for the future production. Then, we calculate the minimum steam flowrate by separated steam cycle and the assumptions corresponding liquid-dominated geothermal in Ulubelu field. The important thing in future production is determine how much make up wells for maintaining the production rate along 30 years project corresponding to demand power capacity in State Electricity Company.

### **3. Result and Analysis**

#### *3.1 Decline Curve Model*

Production in geothermal field is very important to observe, to maintain steam flowrate in generate electricity to be produced. Without production stage, revenue from geothermal energy project is not running. The consequence, production optimizing on geothermal development is very crucial stage to maintain power capacity. Naturally, production in oil and gas will decline corresponding to time as well as geothermal fluids.

The purposes of decline curve analysis is to test decline curve model that used in petroleum industry in geothermal production data and to examine and develop new analysis. Based on production data from control room in liquid-dominated geothermal, we could obtain production decline curve model. But, the data contain scatter. According to Zais (2008), reservoir that correlate with scatter data is cause of rainfall, recharge, earthquake, and subsidence. While, production correlate with scatter data cause of change production schedule, bad well completion, workovers, bad calibration, and bad data collection way.

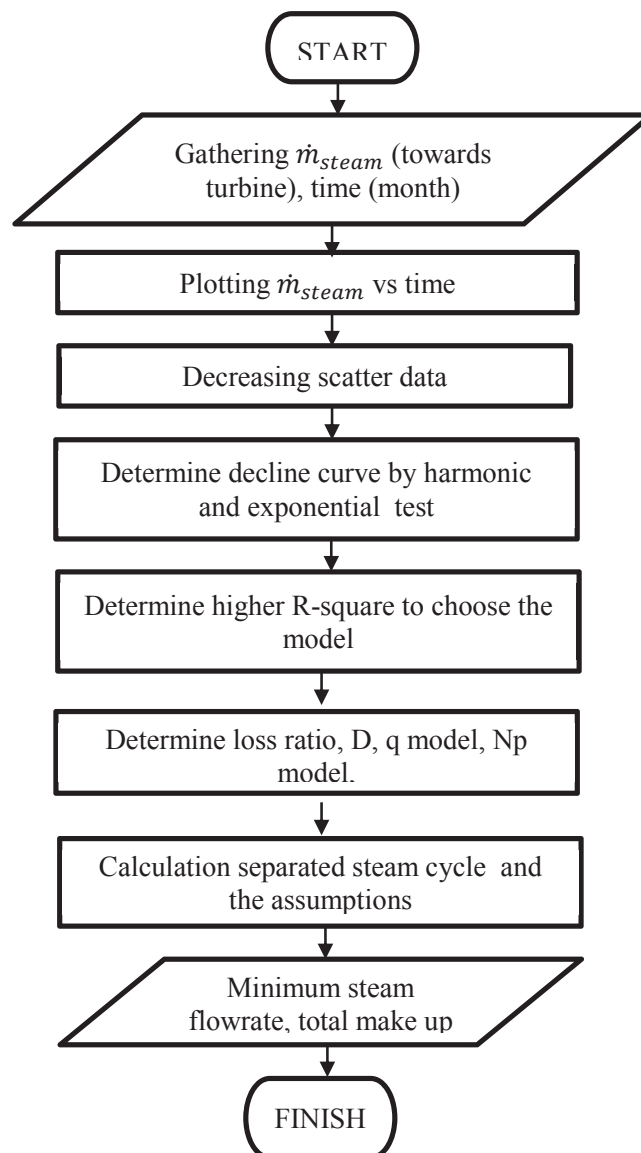
The problems in production data is scatter data. The scatter data is very difficult to be avoided. But the method to decrease scatter data such as (Zais, 2008):

- a. Average production data.
- b. Least square.
- c. Decreasing known effect and trends.
- d. Using knowledge and experience.

In this paper, the decline curve model is specific to steam flowrate toward turbine only. The following below the steps to obtain decline curve model:

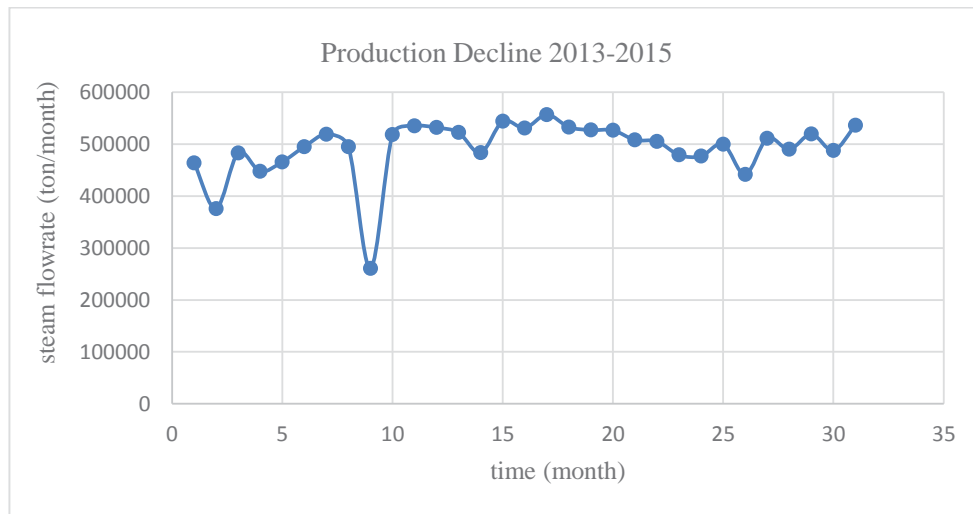
- a. Gather production data especially steam flowrate from 2013-2015.
- b. Make a plot steam flowrate to time.
- c. Selection the data for decreasing scatter.
- d. Find decline curve model with steam flowrate plot in semi log and time in plot log. If the plot approach a linear graphic, the model is exponential model
- e. Try another plot with steam flowrate and time in log plot. If the plot approach a linear graphic, the model is harmonic model.

The following flowchart of developing decline curve model in Ulubelu field:



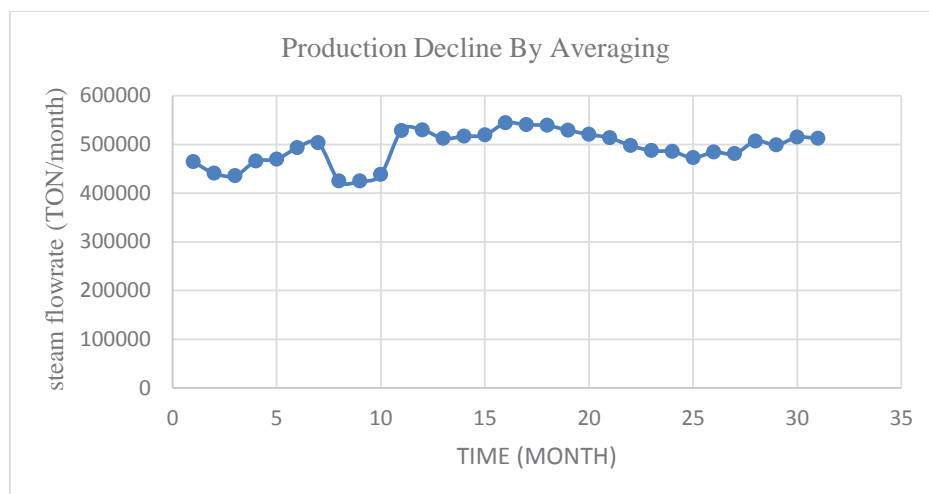
**Figure 1.** Decline Curve Model Flow Chart

Steam flowrate (ton/month) data toward turbine was made each month from 2013-2015. The flowrate is measured from a field by combine two path steam pipe from separator. The following is the result of steam flowrate graphic :



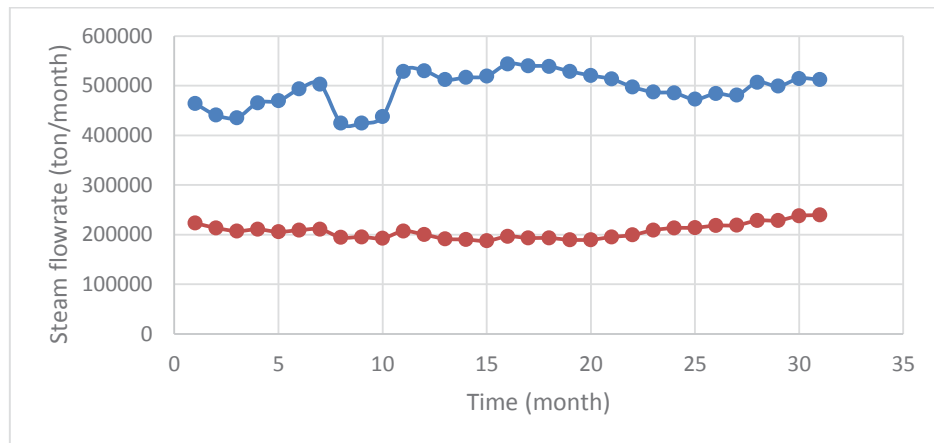
**Figure 2.** Production Decline 2013-2015

Base from figure 1, production data showed scatter so that need smoothing data by averaging the data. The averaging data is divided to 3 intervals. So, the following results of steam flowrate graphic by averaging all data.



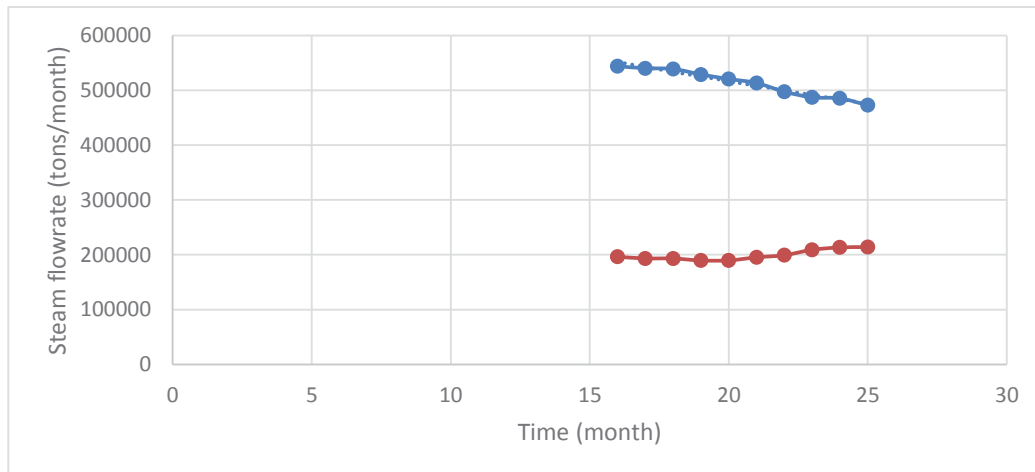
**Figure 3.** Averaging production decline

After averaging the production data, then the data need to be election. The data is chosen by assuming constant reservoir factor, field condition still is not shut, and no additions new well. The following graphic production flow and injection flow:



**Figure 4.** Relation of production and injection flow

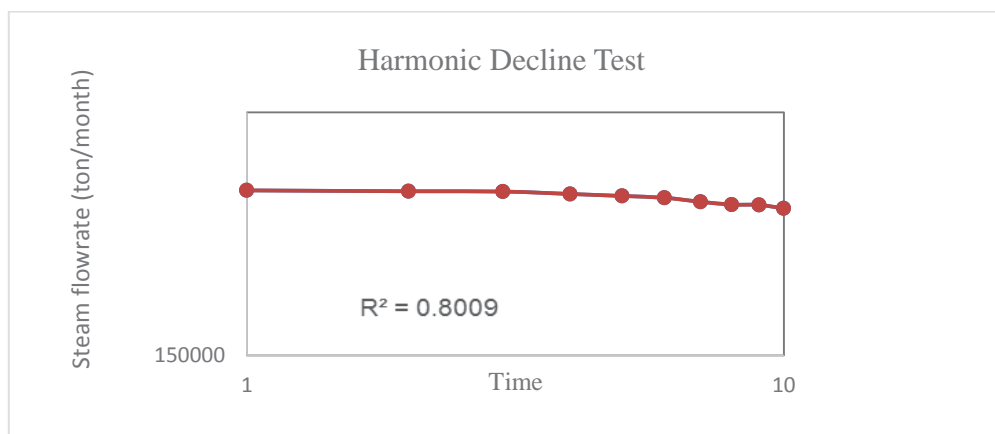
Base of figure 3, field condition is no shut, and no addition, the selection data for curve model is 16<sup>th</sup> to 25<sup>th</sup> month, the following result of is obtained:



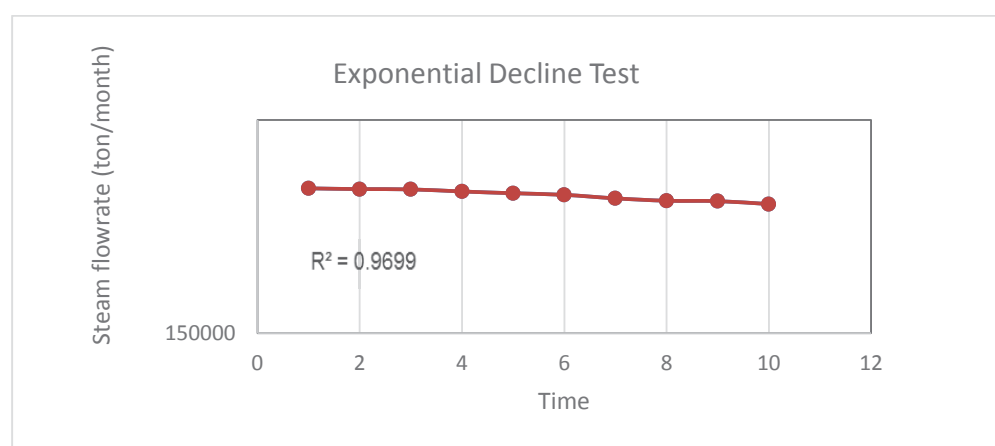
**Figure 5.** The selection data for curve model

The graphic will be used for testing decline curve model. For determining decline curve model, the following test was conducted for determining suitable model between exponential and harmonic model:

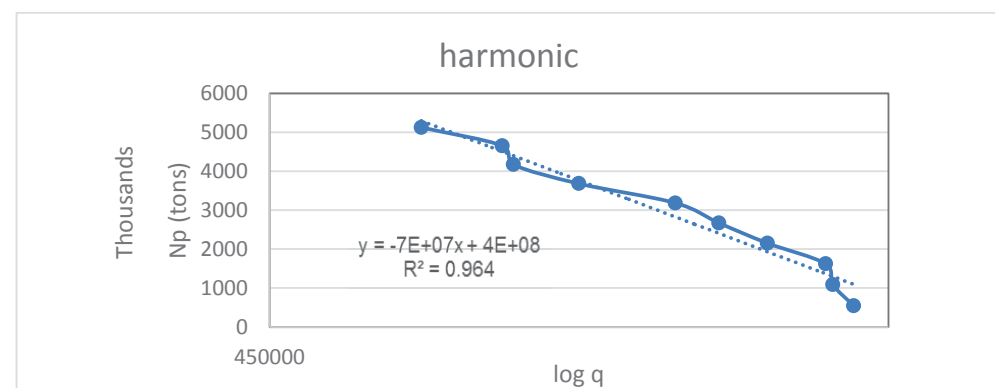
- Production decline figure. 4 is used for testing
- Test harmonic decline by making figure 5 to be axis x and y on log plot.
- Test exponential model by making figure 6 to be axis x on semi log plot and axis y on log plot.
- Determine the graphic that produce linear plot by qualitative and quantitative by R-square value.
- The graphic that produce higher R-square value linear will be production decline model.



**Figure 6.** Log plot harmonic model test

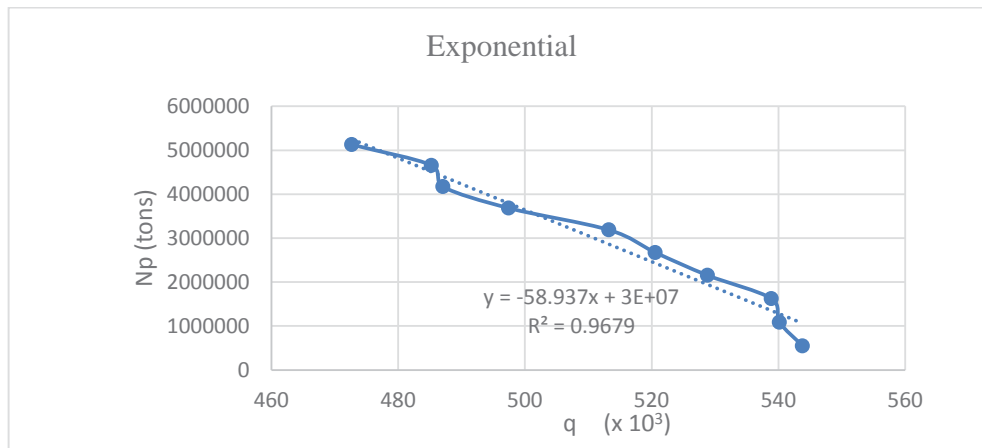


**Figure 7.** Semi log plot exponential testing



**Figure 8.** Test harmonic decline model by quantitatif





**Figure 9.** Test exponential decline model by quantitativ

Test decline curve for exponential model by semi log plot but decline curve for harmonic model used log plot. By trending test in excel, R square value exponential model was be higher than harmonic model. It means exponential model better accurately in linear. So that, model from production data in a geothermal field water dominated system is exponential model.

Then, we will calculate decline rate by firstly calculate loss ratio. Loss ratio is calculated by Arps formula:

$$Loss\ Ratio = \frac{q}{\Delta q / \Delta t} \approx \frac{q}{\Delta q} \quad (1)$$

**Table 1.** Loss ratio production data

Month	Steam flow (tons/month)	Average Steam flow (tons/month)	Loss Ratio
16	530943.3	543836.5	
17	556713.9	540181.7	147.8
18	532887.9	538901.9	421.1
19	527104.0	528852.3	52.6
20	526564.9	520580.5	62.9
21	508072.6	513278.9	70.3
22	505199.2	497470.6	31.5
23	479140.2	487066.9	46.8
24	476861.4	485291.9	273.4
25	499874.2	472688.4	37.5
Average Loss Ratio			127.1

Correlation between loss ratio and decline rate are inversely proportional, where

$$Loss\ Ratio = \frac{1}{D} \quad (2)$$

$$D = \frac{1}{Loss\ Ratio} = \frac{1}{127.1055} \times 100\% = 0.7867\ \% / month$$

Finally, decline rate value from production decline in a Geothermal water dominated system is 0.7867 %/month. This decline rate is effective decline rate. But the type of decline is divided by two are effective decline rate ( $De$ ) and nominal decline rate ( $D$ ). If we can see the characteristic of  $D$  and  $De$ , it prefers used  $D$  because for  $D$  value relatively easy to change time units by multiple or divide with time conversion factor (Asep, 2004).

The following is the correlation between  $De$  and  $D$ :

$$D = -\ln(1 - De) \quad (3)$$

$$D = -\ln(1 - De) = 0.0521 = \frac{0.7899\%}{month} = 9.4 \%/year$$

So that, decline rate value is 9.4 %/year. This decline rate value is called nominal decline rate. The value will be used for forecasting to the future production.

### 3.2 Prediction steam flow and cumulative production in the future

Base of decline rate value, steam flow production can be predicted by exponential decline curve

$$q = q_i e^{-Dt} \quad (4)$$

$$q = 543836.5167e^{-0.007899t}$$

Where,  $t$  is time in month and  $q$  is steam flow in ton/month. By using equation (4) above, then we can predict steam flow in the future. Here  $q_i$  is value steam flow at April 2014. Equation 4 can be assumed that no add wells, no recharge, and no rainfall that can change reservoir factor. While for predicting steam production to the future is:

$$Np = \frac{q_i(1 - e^{-0.007899t})}{0.007899} \quad (5)$$

### 3.3 Calculate minimum steam flow by separated steam cycle

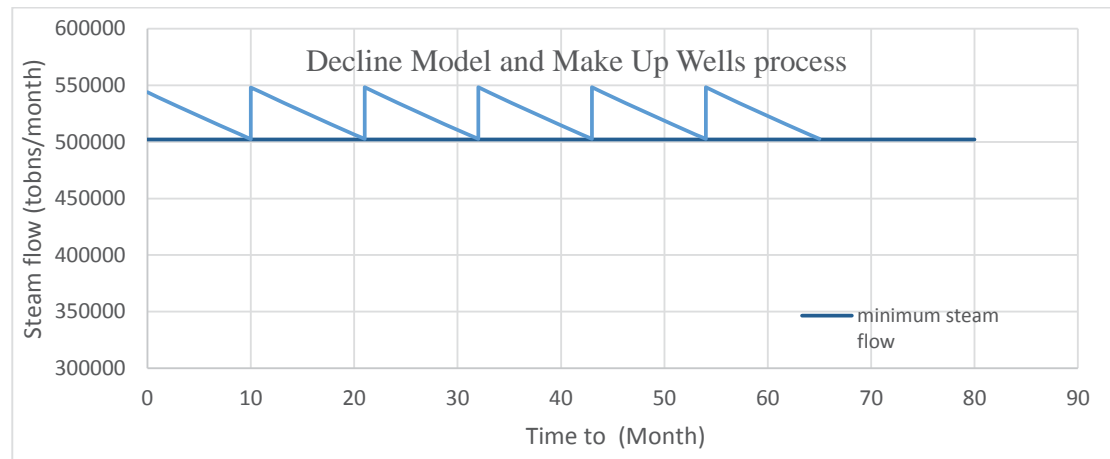
The important thing in geothermal field is to maintain steam flowrate in certain power capacity. A geothermal field must produce 2x55 MWe. It means that we must calculate the minimum steam flow rate to produce the value of electricity to State Electricity Company. To calculate minimum steam flowrate, we used separated system cycle because the field is water dominated (two phase). The assumption to calculate minimum steam flow by separated steam cycle is

- a) Turbine efficiency : 85%
- b) Reservoir temperature : 250°C, single phase liquid
- c) Make up wells produce : 10 MWe/well

Based on calculated separated steam cycle system in appendix I, the minimum steam flow rate required to produce power capacity of 110 MWe is 502018.4 ton/month.

### 3.4 Planning make up wells

The minimum steam flow rate to supply 110 MWe need to be maintained. When the steam flow rate decline to the minimum, a make-up well need to be drilled. Make up well will be done to maintain steam flow along 30 years. The below graphic decline steam flow before and after make up well.



**Figure 10.** Decline model and make up wells

From figure 7, we can analyze that one make up well can maintain steam flow along 11 month average by assuming the well produce 10 MWe/well and decline rate is constant. It means that the geothermal project must drill 32 make up wells totally to maintain steam flow along 30 years production.

#### 4. Conclusion

Decline curve analyses is most important to predict production performance in the future and maintain production to supply 110 MWe along 30 years project. From the results of this study it can be concluded of the following:

- Decline curve model in a geothermal field water dominated is exponential decline model with decline rate 9.4 %/year.
- Prediction for forecasting decline curve in the future based exponential decline get formula :
  - Steam flow forecasting :

$$q = 543836.5167e^{-0.007899t}$$

- Steam production forecasting :  $Np = \frac{q_i(1-e^{-0.007899t})}{0.007899}$
- The minimum steam flow to supply power electricity 110 MWe is 502018.4 ton/month.
  - 32 make up wells will be needed to maintain production along 30 years.

#### 5. Recommendation

This paper recommended for further research as follows:

- Decline curve necessary fluid flowrate data from each well in a field
- Normalized pressure for each well before construct
- Decline production data must be matched to decline curve simulation reservoir

#### 6. References

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## 7. Appendix

The following below, a summary table of calculating separated steam cycle system:

**Table 2.** Calculating separated steam cycle system

<b>Power Capacity</b>	<b>110.00</b>	<b>MWe</b>
<b>Pressure at Well Head</b>	10.00	bar
<b>h5 (at condenser pressure)</b>	2097.47	kJ/kg
<b>h4 (at turbine)</b>	2765.64	kJ/kg
<b>hf@7.5bar</b>	709.38	kJ/kg
<b>hg@7.5bar</b>	2765.64	kJ/kg
<b>hf@10bar</b>	762.68	kJ/kg
<b>hg@10bar</b>	2777.12	kJ/kg
<b>fluid enthalpy at well head</b>	1085.69	kJ/kg
<b>steam fraction at well head</b>	0.16	
<b>steam fraction at separator</b>	0.18	
<b>steam entrophy to turbine (S4)</b>	6.68	kJ/kg K
<b>Sf@condenser</b>	0.61	kJ/kg K
<b>Sg@condenser</b>	8.21	kJ/kg K
<b>steam fraction at condenser</b>	0.80	
<b>hf5 (at condenser pressure)</b>	178.68	kJ/kg
<b>hg5 (at condenser pressure)</b>	2578.30	kJ/kg
<b>hfg5 (at condenser pressure)</b>	2399.62	kJ/kg
<b>Steam flow minimum</b>	193.68	kg/s
<b>Steam flow minimum</b>	502018.40	ton/month
<b>Addition make up a well</b>	17.61	kg/s
<b>Addition make up a well</b>	45638.03	ton/month