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Summary of Historical Production for Nevada Binary Facilities

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Keywords

GETEM, binary power plants, resource production, capacity factor, Nevada

ABSTRACT

The analysis described was initiated to validate inputs used in the US Department of Energy's (DOE) economic modeling tool GETEM (Geothermal Electricity Technology Evaluation Model) by using publically available data to identify production trends at operating geothermal binary facilities in the state of Nevada. Data required for this analysis was obtained from the Nevada Bureau of Mines and Geology (NBMG), whom received the original operator reports from the Nevada Division of Minerals (NDOM). The data from the NBMG was inputted into Excel files that have been uploaded to the DOE's National Geothermal Data System (NGDS). Once data was available in an Excel format, production trends for individual wells and facilities could be established for the periods data was available (thru 2009). Additionally, this analysis identified relationships existing between production (temperature and flow rates), power production and plant conversion efficiencies. The data trends showed that temperature declines have impacted power production and that in some instances operators increased production flow rate to offset power declines. The production temperature trends with time that were identified are being used to update GETEM's default inputs.

Introduction

Geothermal power plants are designed to produce a specified output at a particular set of resource conditions. If those resource conditions vary with time, power output from the plant will also vary. The motivation for this work was to identify trends in resource production with time and to determine whether those trends and their impact were being correctly depicted in GETEM, which accounts for the effect of a declining resource temperature on plant output in its estimates of geothermal power generation costs. The initial focus of this work was to determine whether the default inputs used in GETEM were representative of actual plants, and whether the model's approach to predicting the impact of a declining temperature on power production required revision.

To assess the changes in the productivity of a resource with time, we utilized publically available data obtained from the NBMG web site. This data was in the form of monthly operational reports supplied to the NDOM that contained flow rates and temperatures from individual production wells; in some instances, the monthly power generation for the facility was reported. The initial step in the analysis required inputting this monthly data into spreadsheets which could then be used to manipulate the data and perform calculations needed to establish trends in production and performance. Once the data was into Excel spreadsheets, those files were uploaded to the DOE's NGDS. The data available from NBMG was from the start of reporting for each plant thru 2009. In this paper, we are presenting data from those Nevada binary plants, shown with the red symbols in Figure 1, that have been

Figure 1. Locations of power plants included in this study.

in operation for 10 years or more, as there is only limited data available for the newer plants that have come online since 2005.

Results

The results for this study are provided in the following sets of plots which show the changes in production parameters reported by the operators, as well as values that were calculated from that reported data. In evaluating this information, some screening of the data was performed. Specific parameters were plotted as functions of time for individual wells; those values that were suspicious were checked against the original reports. If confirmed to have been incorrectly entered were corrected. After these corrections, the remaining extreme outliers were tagged and not included in the analysis. We also compared the total produced flow and total injected flow for each month for the individual facilities. If the flow rates were significantly different (>20%), data for that month was not included in the analysis.

Production Temperature

Operators report only the production temperature for individual wells each month. In order to assess how the field production temperature varied with time, an energy balance was performed where the total produced enthalpy for each well was summed to find the total enthalpy for the field. This value was divided by the total production flow to get a flow weighted enthalpy that was then used to determine the fluid temperature for the field. Those monthly temperatures are shown in Figure 2. These calculations were made using NIST RefProp fluid properties.

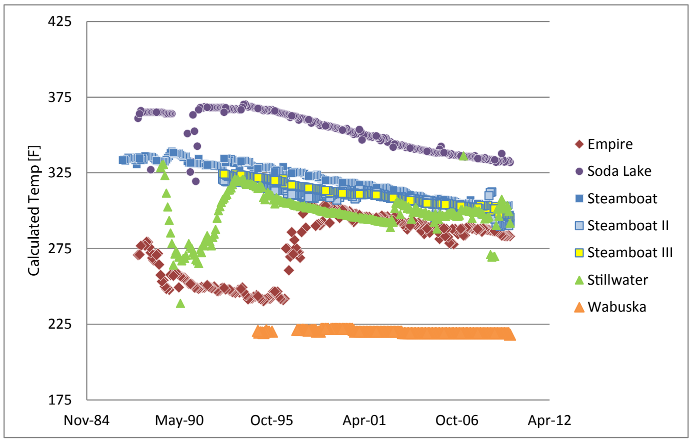

Figure 2. Calculated temperatures for Nevada power plants in operation for greater than 10 years.

This plot shows each facility experienced an overall decline in temperature. Linear trend lines were fit to the data for each facility. The slope of those trend lines represents the daily temperature decline. Table 1 shows the trend line slopes applied to each facility and the corresponding yearly decline rates. The trend lines applied to Empire and Stillwater were altered to omit the large fluctuations that occurred during the early years of operation. Data for Empire was spilt into two sections; the first time period covered December 1987 to August 1996 with a trend line slope of -0.009, the second time period covered September 1997 to December 2009 with a trend line slope of -0.004. A similar process was applied to the Stillwater data; the time period 1994 to 2009 had a trend line slope of -0.0028 shown in the table. The average slope for facilities operating longer than 10 years was -0.00414 °F per day which corresponds to a yearly average decline of -1.51 degrees. For reference, the default used in GETEM would have ranged from -1.1 to -1.8°F annually, with the higher value for the higher temperature resources.

Table 1. Temperature declines for individual facilities.

	Slope of Calculated Temp Trend Line °F per Day	**Yearly Temp Decline (°F)**
Empire (Dec. 1987- Aug. 1996)	-0.009	-3.285
Empire (Sept. 1997- Dec. 2009)	-0.004	-1.46
Soda Lake	-0.0047	-1.7155
Steamboat	-0.0046	-1.679
Steamboat II	-0.0034	-1.241
Steamboat III	-0.0041	-1.4965
Stillwater (Jan. 1994- Dec. 2009)	-0.0028	-1.022
Wabuska	-0.0005	-0.1825

Flow Rate

The reported geothermal production flow from the NV binary facilities is shown in Figure 3.

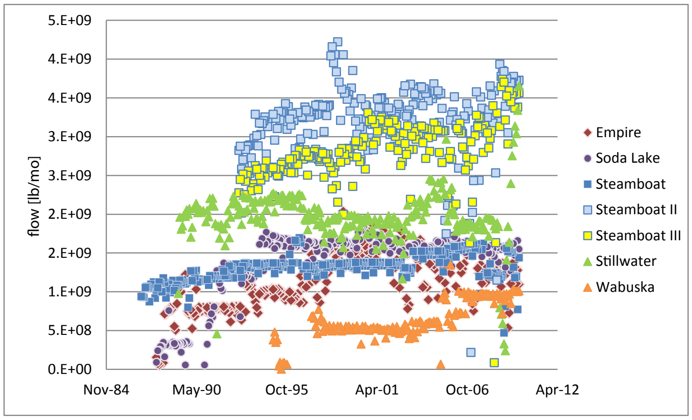

Figure 3. Flow rate for Nevada power plants in operation for greater than 10 years.

Our interpretation of this data is that at some of the facilities operators increased flow in order to mitigate the impact of the declining geothermal fluid temperature on the kWH sales discussed in the next section. In some instances the changes in flow rate correspond to a new plant coming on line at that facility, for example the increase in flow at Stillwater in 2009 corresponds to terminating operation of the existing plant and startup of a new plant.

Power Sales

The reported power sales for Nevada binary plants are shown in Figure 4.

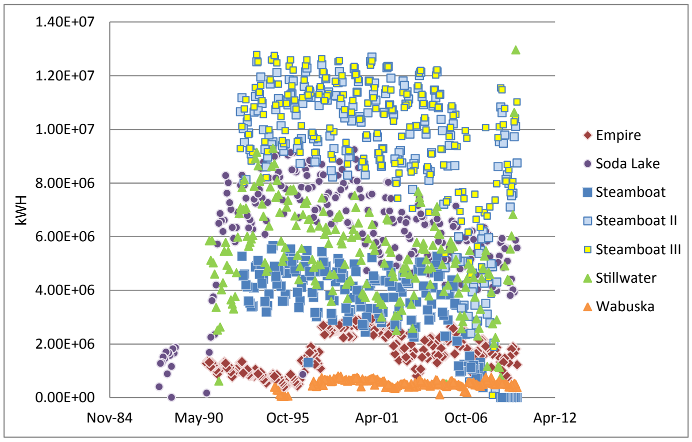

Figure 4. Total monthly kWH to sales for Nevada power plants in operation for greater than 10 years.

Plotted are the reported monthly kWH of sales. Overall, most facilities experienced declining kWH of sales. The data also shows the significant variation in output that occurs over the period of a year for several of these facilities. This variation is most likely due to the effect of higher ambient temperatures during the summer months on these plants which are air-cooled. The data also suggests the decline in power output was less at plants where production flow was increased (Steamboat facilities) than those where flow was more stable (Stillwater). Despite these increases in flow, output at all facilities did decline as the production temperature declined.

Brine Effectiveness

The brine effectiveness is an indicator of how efficiently the plant is converting the geothermal flow to power. It is the power sales for the month divided by the total flow for the month. The values of brine effectiveness that were determined for the NV binary plants are shown in Figure 5.

Brine effectiveness at the different facilities saw overall declines. Brine effectiveness was found by the following equation. The pound per month value in the denominator is the conversion of gallons produced per month to pounds.

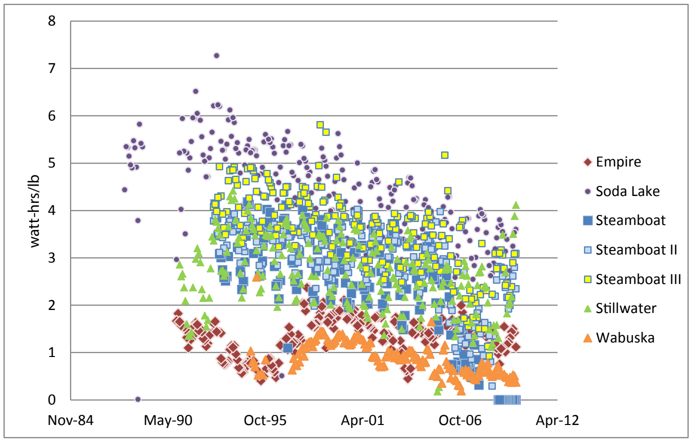

Figure 5. Brine effectiveness for Nevada power plants in operation greater than 10 years.

$$Brine\ effectiveness = \left(\frac{Total\ kWH\ to\ Sales}{\frac{lb}{mo}} \right) * 1000$$

The calculated declines in brine effectiveness were not surprising given the decreases in kWH of sales and/or increases in flow. Though temperatures were not used directly in the brine effectiveness calculations, they do impact the exergy of the brine.

Exergy is a function of the produced fluid temperature. This term varies directly with the resource temperature, and represents the maximum work that could be produced from the geothermal fluid. Hence if the maximum ideal work is decreasing as the temperature decreases, it is expected that the power output (and brine effectiveness) would as well. The exergy of the geothermal fluid is determined using the following relationship (DiPippo, 2012).

$$Exergy = (h - h_0) - T_0 (s - s_0)$$

Effect of Declining Resource Temperature on Power

The effect that resource temperature has on exergy and the impact on power is summarized in Figure 6 below.

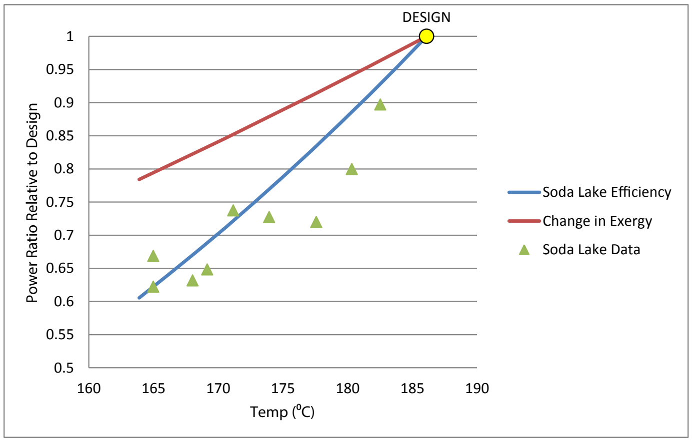

Figure 6. Effect of a declining resource on power.

This analysis was based on conditions at the Soda Lake plant, which had a relatively constant production flow rate and changes in power could be attributed to changes in the geothermal fluid temperature. The temperature range shown reflects the change in the calculated temperature of the produced fluid since the start of operation in April of 1995. The impact of the decreasing brine temperature on exergy shown in this figure is determined using an ambient temperature of 10°C. This change in exergy represents the impact that the declining production temperature would have on power if the 2nd law efficiency remained constant. The 2nd law efficiency is a measure of how efficiently the plant converts exergy to power; it can be expressed as

$$2^{nd}\ law\ efficiency = \frac{Power}{Exergy}$$

Data from the Soda Lake plant is plotted for plant operation with ambient temperatures of ~10°C. This data falls below the curve depicting the change in exergy (red curve), indicating that as the production temperature decreased, the 2nd law efficiency also decreased. The 2nd law efficiencies were calculated for the Soda Lake plant, and a trend line found that depicted the effect of temperature on this conversion efficiency. This trend line was applied to the fluid's exergy to show the impact of the declining 2nd law efficiency on power output (shown by the blue curve in Figure 6). By including the effect of temperature on 2nd law efficiency (Soda Lake Efficiency curve) a better match is obtained with the operator's reported power. The approach that is used in GETEM is similar; the exergy and 2nd law efficiency are calculated based on the production temperature at a given point in the operating life of the plant, and then used to estimate the plant output.

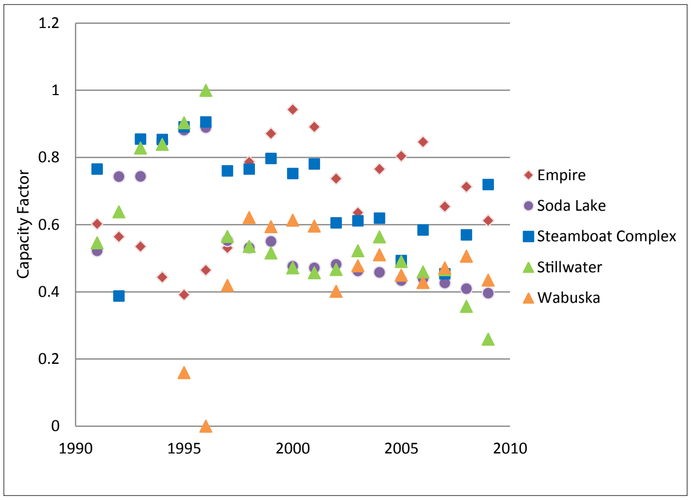

Figure 7. Yearly reported gross capacity factors for Nevada binary facilities.

Capacity Factor

Figure 7 gives the yearly gross capacity factors for the different facilities. An important aspect to note is the magnitude of the capacity factors shown is not necessarily indicative of the performance of an actual plant. This is because of the uncertainty in the power that is reported (sales, net, gross, nameplate), and whether this power is consistently reported over the entire period.

The following equation was used to calculate the gross capacity factor ratings.

$$Gross\ Capcity\ Factor = \frac{Reported\ MW - hrs\ Produced}{\left(Nameplate\ Capacity * 8760\right)}$$

From this equation one can see the obvious relationship between power produced and capacity factor. This relationship can be extended to resource temperature in the sense that declining resource temperature is the main cause of declining power production.

As shown in Figure 7, all facilities saw declines in their capacity factors which could be largely attributed to temperature decline. Stillwater saw the largest difference between maximum and minimum capacity factors at approximately 0.75. Some of the fluctuations observed in capacity factors could be due to changes in the power plant configurations; Stillwater for example exhibits its lowest capacity factor in 2009, which corresponds to the startup of a new power plant with a nameplate capacity of 47.2 MW (an increase in nameplate capacity from 21 MW in 2008).

The capacity ratings used in the denominator of the above equation were acquired from the NBMG Special Publications for the years 1991 to 2009.These documents can be found at the following link http://www.nbmg.unr.edu/dox/dox.htm. The data available is reported as three types of capacity; production, equipment, and nameplate. Years 1991 to 1997 provided the production capacity. 1998 to 2007 provided equipment capacity, and years 2008 and 2009 supplied the nameplate capacity. Though the 1997 capacity was reported as production capacity, it differed from production capacities reported in earlier years and more closely resembled the equipment capacities subsequently reported. We assumed in 1997 the production capacity listed should have been reported as equipment capacity. The step change occurring between years 1996 and 1997 is due to the definition change in reported capacity factors. This change is very apparent in the Soda Lake data shown in Figure 8 where the capacity factor drops from ~90% to less than 60% .

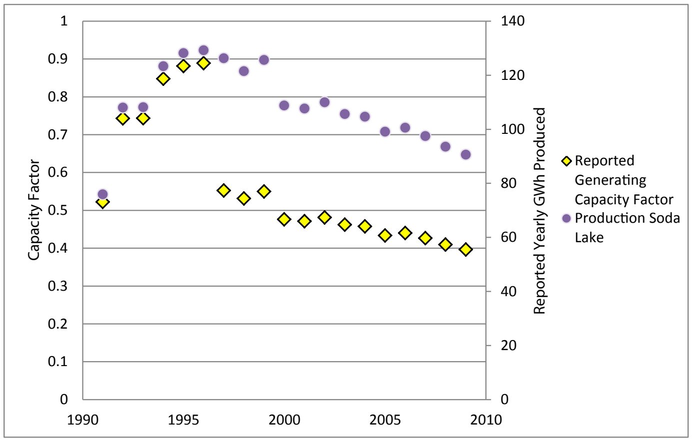

Figure 8. Yearly capacity factors for the Soda Lake facility.

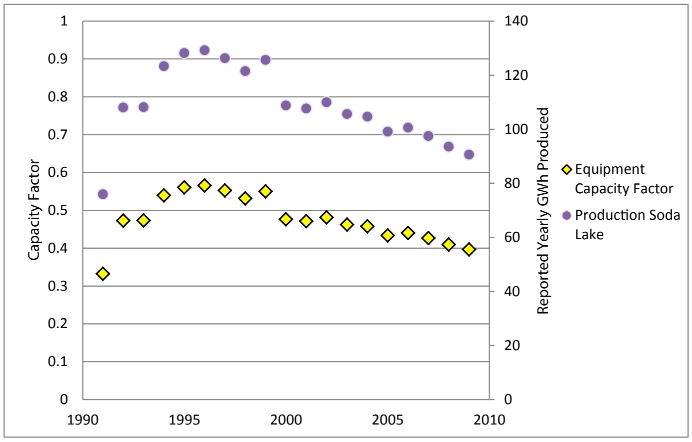

Figure 9. Adjusted yearly capacity factors for the Soda Lake facility.

To illustrate the effects of different capacity definitions, capacity factors for Soda Lake were calculated for years 1991 to 1996 using the 1998 equipment rating of 26.1 MW instead of the reported production capacity. Figure 9 demonstrates this adjustment. With the adjusted capacity ratings for 1991 to 1996, there is a more obvious relationship between the capacity factor and power production.

These two figures illustrate that the definition used for generation capacity (the denominator in the capacity factor definition) has a significant impact on the magnitude of the capacity factor. Figure 9 shows that when a consistent definition is used, the capacity factor trends and the power production trends are consistent (as they should be), and that both decline as the resource temperature declined.

Conclusion

Some initial conclusions are as follows.

- Nearly all plants experienced some level of temperature decline; the maximum decline rate observed was -3.285 °F per year at the Stillwater facility between December 1987 and August 1996, the minimum decline of -0.1825 °F per year was at the Wabuska facility, and an average for the facilities analyzed in this paper was -1.51 °F per year. With declining production temperatures, one can expect to experience kWH of sales declines as well.
- Operators typically increased the flow rates at the facilities to mitigate the sales losses. The data shows that increasing flow rate provided a benefit initially, however at some point power sales declined in conjunction with temperature declines.
- The definition of generating capacity has a significant impact on the magnitude of a plant's capacity factor. If a consistent definition is used, the changes in capacity factor are an indicator of how a declining resource temperature is impacting power production.

Acknowledgement

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