Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Power Potential Assessment of the North West Sabalan Geothermal Field, Iran

FarhadAbdollahzadehbina, SoheilPorkhial, ParnazJohariSefid

SUNA – Renewable Energy Organization of Iran, PoonakeBakhtari Ave., ShahrakeGhodsP.O.Box 14155-6398, TehranIRAN

Abdollahzadeh_bina@yahoo.com

Keywords: Geothermal, Volumetric assessment, Monte Carlo, Sabalan

ABSTRACT

An important factor in a geothermal assessment is the assessment of the volume of the geothermal system in question. For the volumetric method, we assume, for simplicity, that the volume is a box, with a surface area in the xy plane and thickness z1-z0 along the z-axis. According to field data, which are received from ten deep and one shallow exploration and delineation wells, geochemistry and geophysical studies ; this work presents a comprehensive review of the theoretical background and methodology used in volumetric assessment. The volumetric method using the Monte Carlo simulation was applied to estimate the geothermal power potential of the Sabalan geothermal field given three scenarios of 25, 50 and 100 years duration.

1. INTRODUCTION

North West Sabalan (NWS) geothermal field is located in the Sabalan high mountain and the north-west of Iran in Ardabil Province, its distance from Tehran is 859 km, and the distance to Tabriz (one of the large industry cities) is 160 km (Figure 1). The Renewable Energy Organization of Iran has identified a potentially viable geothermal resource at Mt Sabalan.

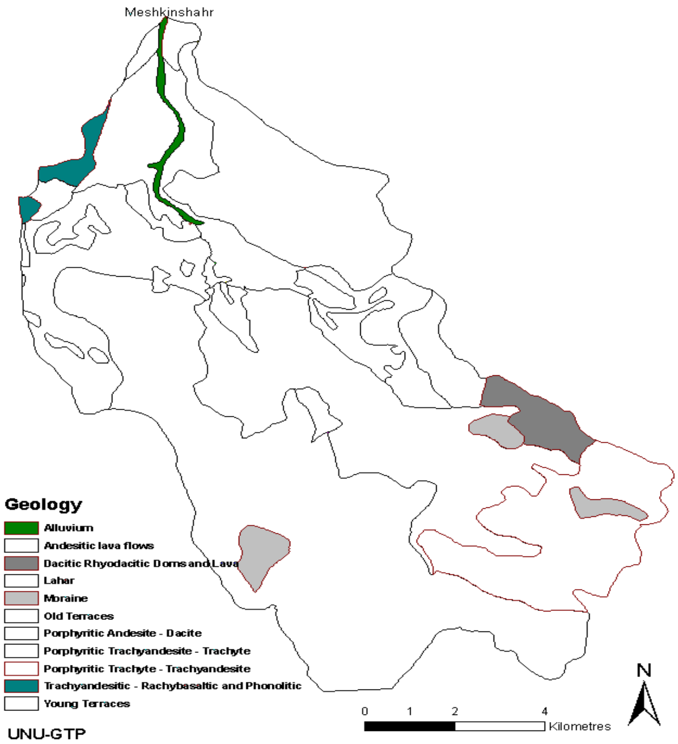

Figure 1: Geological map of the Sabalan – Meshkin Shahr prospect (mod. from Yousefi-Sahzabi, 2004)

2. RESERVOIR ASSESSMENT

2.1 Interpretation of temperature logs

Determining the temperature distribution within a geothermal system is a fundamental requirement of any resource assessment study. The temperature distribution is probably the most useful information that can be obtained as it indicates both the quality of the resource and the fluid flow paths within the reservoir. To determine the sub-surface temperature distribution, it is first necessary to interpret the measured temperature surveys in the wells to establish the 'stable' reservoir conditions as a function of depth for each well i.e. finding the rock temperature and the initial pressure in the reservoir. Contour plots and vertical cross sections can then be prepared at selected depths and locations to show how the temperature varies within the reservoir, horizontally and vertically. These plots are useful in showing how hot and cold fluids interact within the geothermal system and are therefore very important in the formulation of the hydro-geological model of the system. The estimated stable temperature data have been used to construct temperature cross-section map where data was available from the 10 deep wells. A cross-section (Figure 2) generated by the Surfer software is shown for comparison

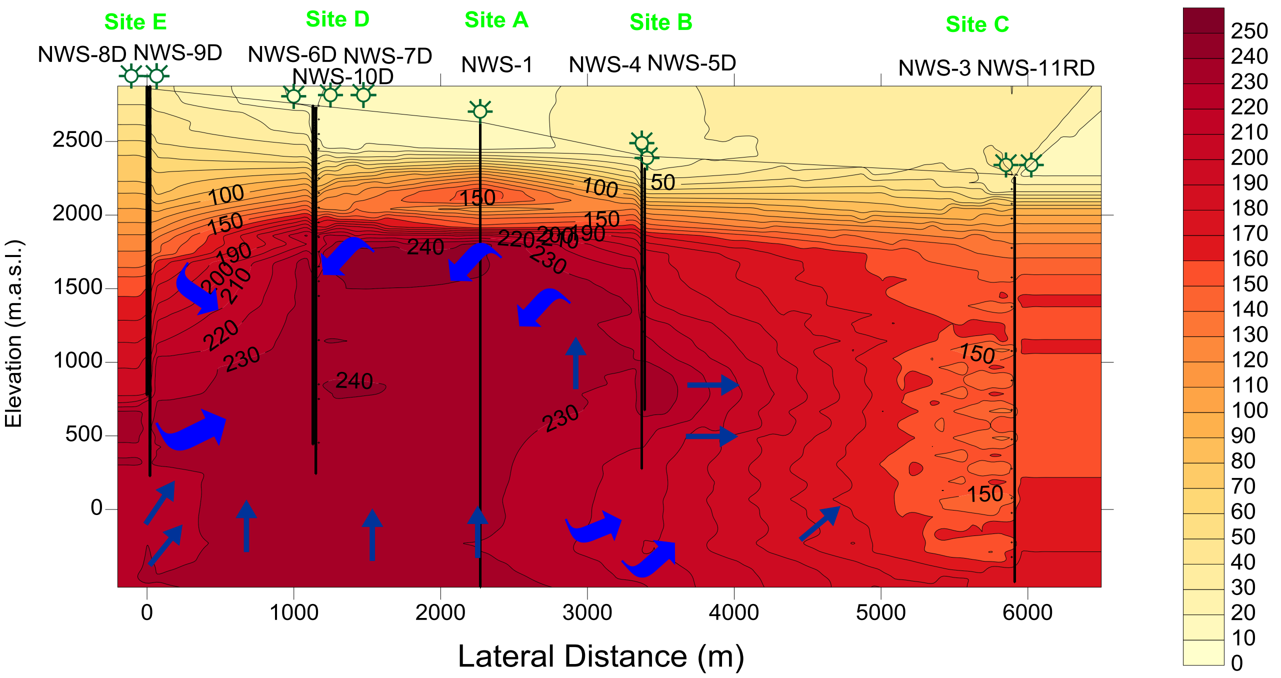

Figure 2: Sabalan geothermal field temperature cross section

2.2 Theory

An important factor in a geothermal assessment is an assessment of the volume of the geothermal system in question using the volumetric method. We assume, for simplicity, that the volume is a box. In this report this box has a surface area A in the xy plane and height (thickness) z_1-z_0 along the z-axis, where z_1 and z_0 are the lower and upper limit of the geothermal system, respectively. When the volume of the geothermal system has been assessed the choice has to be made on how to calculate the useable heat that the system contains. For simplicity, it can be assumed that the heat capacity and temperature are homogeneous in the xy plane and are only dependent on depth. The heat content of the system can then be calculated by integrating the product of the estimated heat capacity per unit-volume C (z) and the difference between the estimated temperature curve T (z) in the system and the cut-off temperature T_0. The cut-off temperature is the temperature of the state from which the heat is integrated. This can be the outdoor temperature, minimum temperature for electric production, absolute zero temperature etc. The choice of T (z) depends on how one calculates the usable energy. We therefore get the heat energy contained in the geothermal system as:

$$Q = A\int_{z_0}^{z_1} C(z)[T(z) - T_0]\,dz (1)$$

Only a small portion of the total heat in the system is recoverable and therefore we define a recovery factor, R, which is the ratio of the heat which we can recover to the total heat in the system. The recoverable heat is therefore

$$Q_R = RQ (2)$$

The heat according to equation (1) can be calculated in two ways. The first method is to integrate over the temperature curve and the second method is assuming that the temperature is also homogeneous in the z direction and therefore constant over the whole volume. This constant would be some mean temperature for the volume. The first method is appropriate if it is believed that the temperature curve is nonlinear. But if it is believed that the temperature curve is close to being linear the second method would be more appropriate as the constant temperature would be the average temperature of the system. For simplicity the heat capacity per unit-volume will be taken as homogenous for the whole system and written as

$$C = S_R(1-\varphi)\rho_R + S_w\varphi\rho_w (3)$$

Where S_R and $S_w$are the specific heat of rock and water, respectively, ρ_R and$\rho_w$density of rock and water, respectively, and $\varphi$is the porosity of the rock. For the case of a nonlinear temperature curve, which will be assumed from here on, it is convenient to assume that the temperature curve in the system follows a curve shaped like the boiling point curve (James, 1970)

$$T(z) = x.69.56(z + z_{Delta})^{0.2085} \ (4)$$

Here$x$is a ratio factor running from zero to one describing the deviation from the true boiling curve, $z_{Delta}$is a translation in the z direction in order to fulfil the upper boundary conditions, T_{Z0} at z_0. Then we can write the recoverable heat described in equation (2) as

$$Q_R = RAC\int_{z_0}^{z_1}[T(z) - T_0]\,dz (5)$$

From the recoverable heat of the geothermal system, we can only utilise a small portion for electric production. We therefore define an electric utilization constant $\eta_e$which gives us the electric energy

$$Q_e = \eta_e Q_R (6)$$

And the electric power

$$P = \frac{Q_e}{t} (7)$$

Where, t is the production time of the electric power in seconds.

2.3. Monte Carlo Calculations

The variables used in the volumetric method are often shrouded with uncertainty and therefore it is necessary to define a probability distribution for these variables. By choosing one random value for each variable out of that probability distribution, one possible outcome of the volumetric method can be calculated. If this process is then repeated several times a discreet probability distribution for the outcome begins to form. This method of calculation is often named Monte Carlo calculation after the Monte Carlo casino where similar method is used for wealth distribution. To form the discrete distribution for the outcome we divide the interval of possible outcomes into equally long subintervals.The probability that the real outcome is in a particular subinterval is the ratio of possible outcomes that fall in that subinterval to the total number of possible outcomes that have been calculated. With the discrete probability distribution an opportunity emerges to evaluate the probability for the outcome to fall into a particular interval.

2.4. Evaluation of Variables

To be able to perform the volumetric calculations we must estimate the value or probability distribution for the following variables:

- ✓ Surface area of the geothermal system, A.
- ✓ Thickness of the system, z_1-z_0.
- ✓ Porosity of the rock, φ.
- ✓ Mean physical characteristics of the rock and water in the system, that is the specific heat and density of the rock and water, S_R,S_w, $\rho_R$and ρ_w.
- ✓ Heat distribution through the container, T (z). This means the deviation ratio from the boiling curve, x, and the boundary conditionz_{Delta}.
- ✓ Recovery factor, R.
- ✓ Cut-off temperature, T_0.

These variables will give the heat recoverable from the system. To be able to evaluate the electric production capacity of the reservoir we also need values for the following variables

- ✓ Electric conversion coefficient, ηe.
- ✓ Electric production time, t.

From the interpretation of the MT data and the surface geology, we get the volume variables, the area A and lower depth z_1. The system is mainly made of par gneiss. Therefore, the range of values for porosity, rock density and the specific heat of the rock of the reservoir are chosen to be the same as for metamorphic rock (Freeze and Cherry, 1979b). The recovery factor is a function of the porosity, as the heat is more difficult to extract from the rock with lower porosity. Low values of porosity are expected for intrusive volcanic rock. For the upper layer the mean porosity used was 0.10 and the corresponding recovery factor used was 25%. For the deeper layers the mean porosity was 0.08 and the recovery factor used was 20%. The conversion efficiency is a function of the resource mean temperature and values between 10 and 11% were used in the calculations.

In figure 3, the temperature measurements in boreholes in the area along with some possible temperature curves T (z) are shown. From this figure we draw a conclusion about the distribution of the boiling curve ratio, x, for our model. The boundary condition $Z_{Delta}$is calculated from the annual mean surface temperature, which is taken to be 25 °C. The cut-off temperature is chosen to be 180°C (Wilcox, 2006). To estimate possible electric power production we consider three production time scenarios, 25, 50 and 100 years. A summary of the areas and also the temperatures, porosity and other values used is given in table 1.

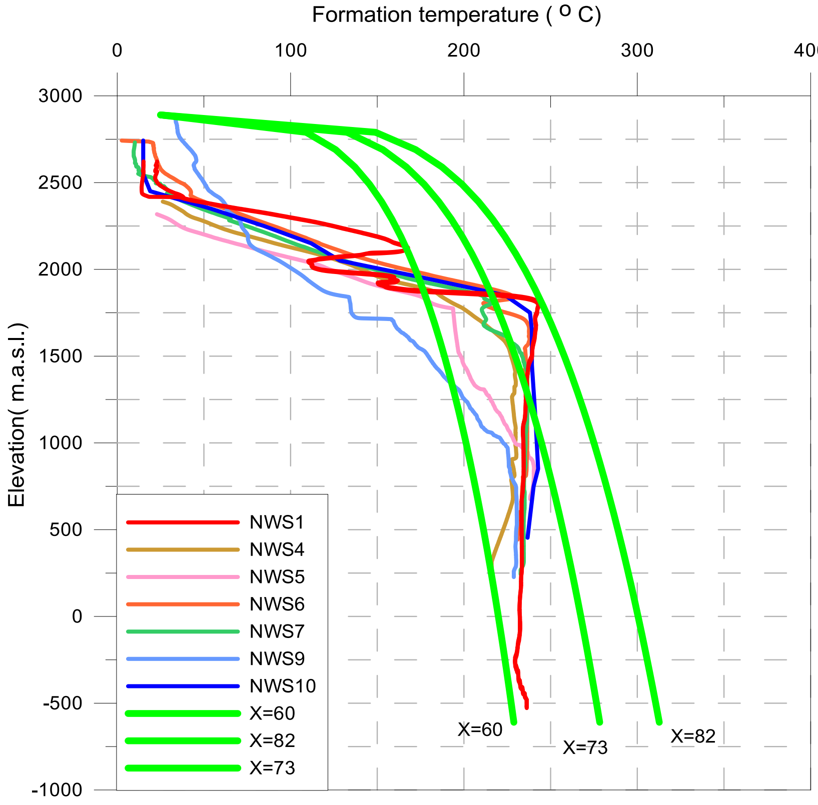

Figure 3: Formation temperature measured and three temperature curves. These curves are with the minimum, most likely and maximum value of the boiling curve ratio.

Table 1: Values and distributions of the variables in the volumetric method.

Description	Variable	Distribution type	Min value	Most probable value	Max value
Upper depth (m)	Z_0	fixed	N/A	0	N/A
Lower depth (m)	Z_1	Triangular dist	2000	2500	3000
Surface area (km^2)	A	Triangular dist	10	19	30
Cut off Temperature (^{o}C)	T_0	fixed	N/A	180	N/A
Porosity (%)	φ	Triangular dist.	4	8	12
Specific heat of rock J/(kgm^3)	S_R	Triangular dist	900	950	980
Density of rock (kg/m^3)	ρ_R	fixed	N/A	2500	N/A
Specific heat of water J/(kgm^3)	S_W	fixed	N/A	4400	N/A
Density of water (kg/m^3)	ρ_W	fixed	N/A	800	N/A
Boiling curve ratio (%)	x	Triangular dist	60	73	82
Recovery factor (%)	R	Triangular dist	15	20	25
Convergence efficiency (%)	ηe	fixed	N/A	11	N/A
Production time (Years)	t	fixed	N/A	25, 50 or 100	N/A

2.5. Results of the volumetric calculations

An estimate of the electric power, which could be produced from the recoverable heat with cut-off temperature of 180°C from the Sabalan geothermal reservoir, has been calculated according to equation (7). This was done for three production time scenarios. The results are presented as a discreet cumulative probability distribution, seen in figures 4, 5 and 6. Each figure consists of 100,000 random outcomes. From these random outcomes miscellaneous statistical information can be found. These include the likeliest outcome, 90% confidence interval, mean and median of the outcomes, standard deviation and where the 90% limit for the cumulative probability lies. These statistics are presented in table 2 for each of the three production periods.

According to the statistics of the probability distribution it is seen that the volumetric model predicts that with 90 % confidence the power production is around 58 MWe for 25 years, around 30 MWe for 50 years and around 16 MWe for 100 years.

It should be emphasized that the great range of values resulting from the Monte Carlo calculations simply reflects the uncertainty in the results obtained by the volumetric assessment method. It is primarily caused by uncertainty in the size, temperature and recovery factor for the Sabalan geothermal reservoir resource. A lower limit for the recovery factor of 15% is used, reflecting uncertainties in porosity and recharge. If reinjection will be applied during utilization to supplement natural recharge a higher lower limit for the recovery factor can be used, raising the lower limit for the production capacity estimate.

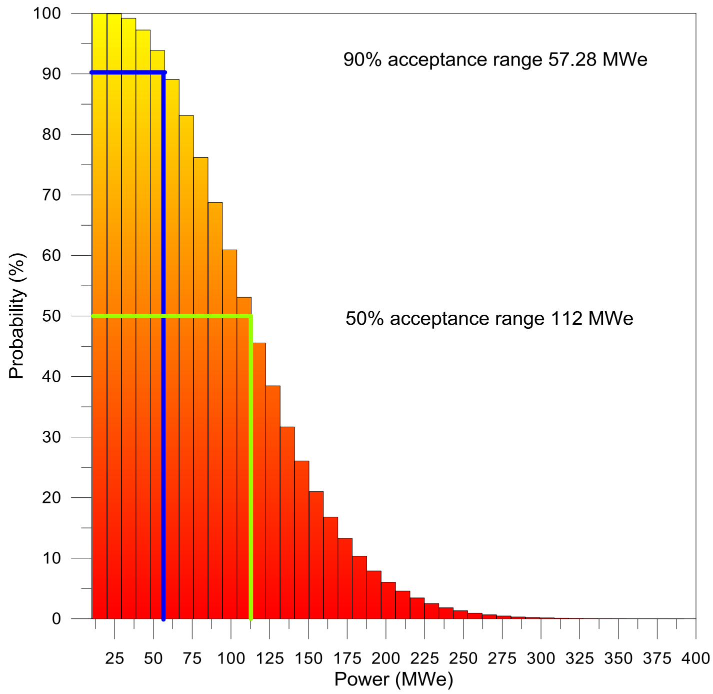

Figure 4: Cumulative probability distribution for electric power production for 25 years.

Table 2: Statistical parameters for the Sabalan geothermal field simulated by the Monte Carlo method.

Statistical size	Values [MWe](for 25 years)	Values [MWe](for 50 years)	Values [MWe](for 100 years)
90% confidence	57.2	29.6	15.4
Mean	113.5	56.9	28.4
Median	107.6	53.8	26.9
Standard deviation	48.7	24.2	12.1

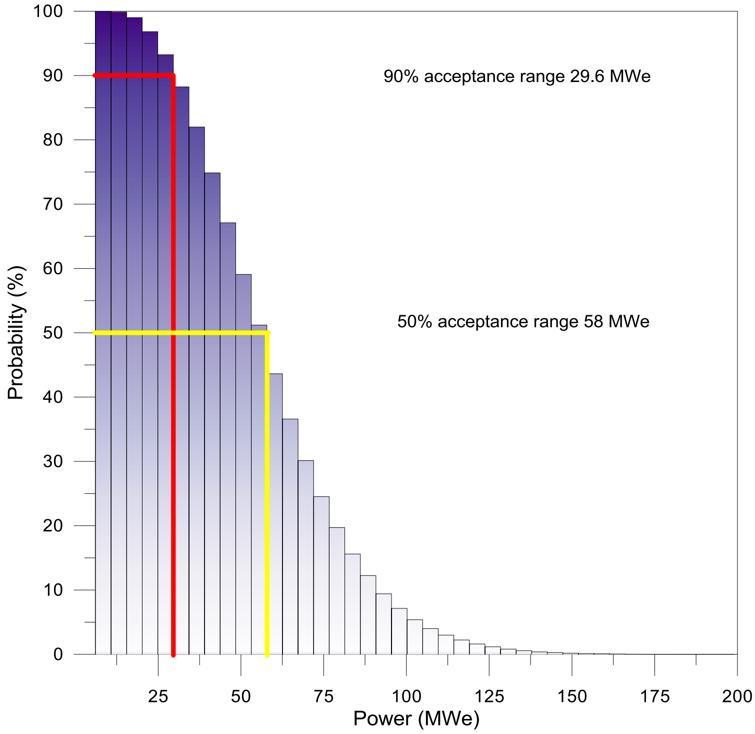

Figure 5: Cumulative probability distribution for electric power production for 50 years.

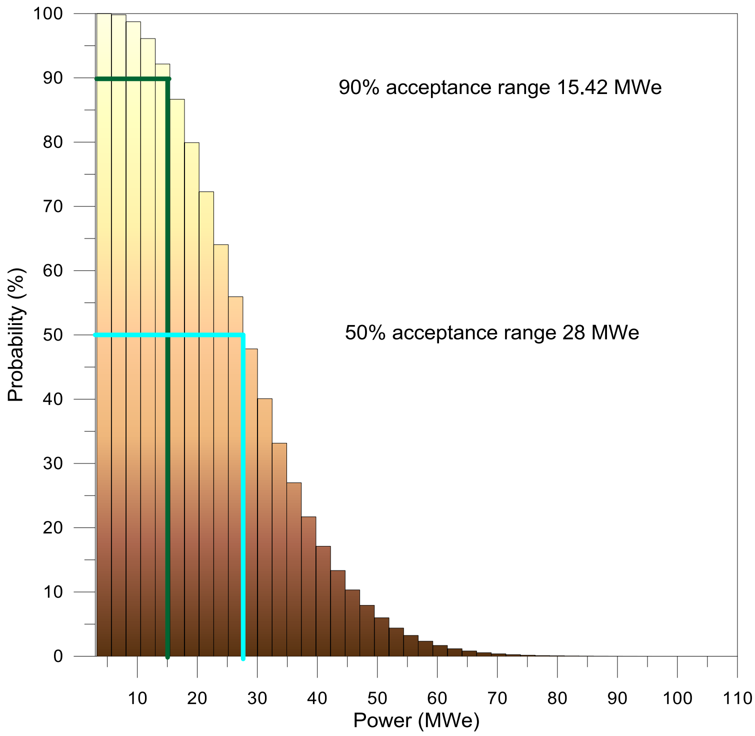

Figure 6: Cumulative probability distribution for electric power production for 100 years.

CONCLUSION

A Monte Carlo volumetric capacity assessment, based on the available data, has been performed. An estimate for the electric power, which can be produced from the recoverable heat in the geothermal region, has been calculated. According to the results, the electrical power capacity will be, with 90% confidence, 58 MWe if the recoverable heat is used for 25 years. It will be 30 MWe if it is used for 50 years and 16 MWe if it is used for 100 years. The great range of these estimates simply reflects the uncertainty in the size, temperature and recovery factor for the Sabalan resource. For example a lower limit for the recovery factor of 15% isused, and if reinjection will be applied during utilization a higher lower limit for the recovery factor can be used, raising the lower limit for the electrical power capacity estimate.

REFERENCES

Freeze, R. A. and Cherry, J. A. (1979b). http://web.ead.anl.gov/resrad/datacoll/porosity

James, R. (1970). *Factors controlling borehole performance*.Geothermics, 2, 2: 1502–1515.

Wilcox, G. (Editor). (2006). The future of geothermal energy, impact of enhanced geothermal systems [EGS] on the United Sates in the 21. Century.Massachusetts Institute of Technology.