USE OF ALTERNATE METHODS FOR ESTIMATING WATER CONTENT IN THE KIZILDERE GEOTHERMAL FIELD

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SUMMARY- The reserve determination methodology, generally utilized for oil reservoirs, was carried out to estimate water in-place in the Kizildere geothermal reservoir in Turkey. In the past, the water in-place had been estimated volumetrically on the basis of geological and geophysical data. This study involves in the volumetric estimation of water in-place through the stochastic approach. For comparison, decline curve analysis methods, based on production history data, were used to estimate water in-place. A material balance technique was utilized for the same purpose. A long-term production test analysis was also employed as reservoir limit test for the estimation. All of these studies have revealed consistent values of water in-place. In conclusion, this study has shown that the reservoir estimation methods developed for oil reservoirs can also be used for geothermal reservoirs.

1. INTRODUCTION

Located in the eastern extreme of the B. Menderes graben, where it intersects with Gediz and Çürüksu grabens, the Kizildere geothermal field is a liquid dominated reservoir with temperatures of 195-212°C at depths of 300-800 m. The field was discovered in mid 1960's, and 17 wells were drilled during the next decade to develop the field and to assess its capacity. A power plant of 20 MW_e energy generation capacity fed by 6 production wells was installed at the field and power generation started in 1984, Three additional production wells were drilled two years later to increase the steam production. The field has been generating approximately 7.5 MW_e of power for the last 14 years.

Two stratigraphically separate zones in the field were initially identified as reservoirs during the exploratory stage; a shallow one in Miocene limestones with temperatures of 196-200°C and moderate permeability, and a deeper one, a few hundred meters deep, in Paleozoic marbles with temperatures of 200-212°C and high permeability. The limestones are discontinuous, and, therefore, are not encountered in all wells. The marbles are much more continuous and thicker with better permeability. The deeper marble zone was targeted for exploitation. Wells KD-1, KD-2, KD-3, KD-4, KD-12, and KD-111 tap the shallow zone, and the rest tap the deeper part of the geothermal reservoir. Encountered permeabilities at the drilled wells vary considerably. In particular, the wells drilled in the area delimited by geological and geophysical studies, show much higher permeability. Reservoir rocks, especially marbles, do not have primary porosity and permeability, but secondary porosity and permeability only.

Knowledge of the volume of water existing in Kizildere geothermal reservoir is extremely important because it will affect the ultimate cumulative production and its recoverable heat, and consequently the electrical energy to be generated. Eventually, such information will play a pivotal role in the reservoir studies of this field. In the following sections the amount of water in place is investigated by the different methods stated above, and their results are reported.

2. METHODOLOGY

In the oil industry the liquid in-place in a reservoir is estimated through the time dependent methods, which yield reliable results. Thus, the more the production information and data are obtained over time, the more reliable the reserve estimations will become. However, since its discovery only the simple material balance and geology based volumetric reserve estimations had been realized for Kizildere field.

Different methods are used for the estimation of the liquid filled volume depending on the stage of the field development. In the early stages, when geological and geophysical data and perhaps few wells with related information are available, the volumetric method is preferred. In later stages, as the abundant pressure and production data become available, other methods, decline curve analysis, material balance technique and production performance are applied. These conventional methods are carried out to determine liquid in-place in the oil industry. In this study these methods are applied to Kizildere geothermal field for the estimation of water-in place.

The most reliable results are achieved when either of the two approaches, deterministic and stochastic, are used. Note that the reliability and the quality of the results, obtained by either of the approaches, are strongly influenced by the quality ofthe data.

3. VOLUMETRIC ESTIMATIONS

Dominco (1974) first carried out the volumetric estimation of water in-place in Kizildere field using the deterministic approach. He reported a minimum volume of $600x10^6$ m^3 of water in-place. More information was obtained by drilling more wells and additional studies have been conducted since then. Yet, the information on field boundaries, reservoir thickness, and porosity of the rocks comprising the reservoir are still uncertain.

A probabilistic study quantifies the uncertainty in the reserve estimates by using distributions describing the range of values that could possibly occur for each variable and produces relative frequency of the values occurring within that range. The combined relative frequency curve is then obtained by Monte Carlo simulation to describe the possible range of occurrences for the water in-place and the associated probability of occurrence of each of the volumes within that range. Recent studies, Serpen et al., 1995 and Serpen et al., 1998, disclosed a new data set on the field boundaries and reservoir rock porosity, These newly acquired data are converted into the form of distributions by using a stochastic study. Afterwards, the distributions are utilized in Monte Carlo simulation runs. It was noted that the pore volume is strongly dependent on the type of (primaryor secondary) porosity and its variations. The results of two separate simulation runs, one for the minimum and the other for the maximum values of distributions, are illustrated in Figure 1.

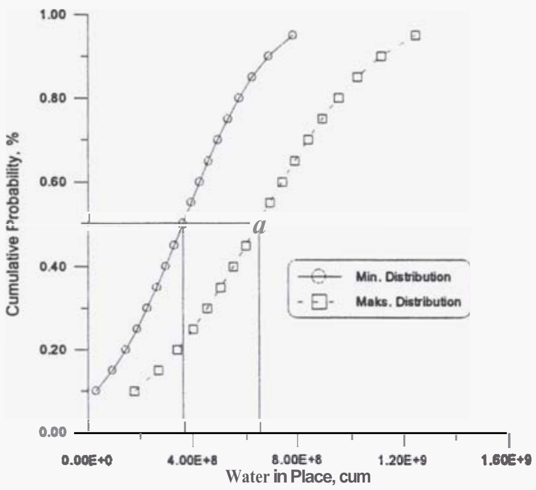

Figure 1. Distribution of water in-place for minimum values.

A final distribution of water in-place is obtained by employing the ***"variable arguments for distribution jiinction"*** technique that utilizes the two functions in Figure 1. The resultant final distribution of water reserve is shown in Figure 2. The expected value of water in-place is found as $540x10^6$ m^3 of water fiom the mean value of this last distribution.

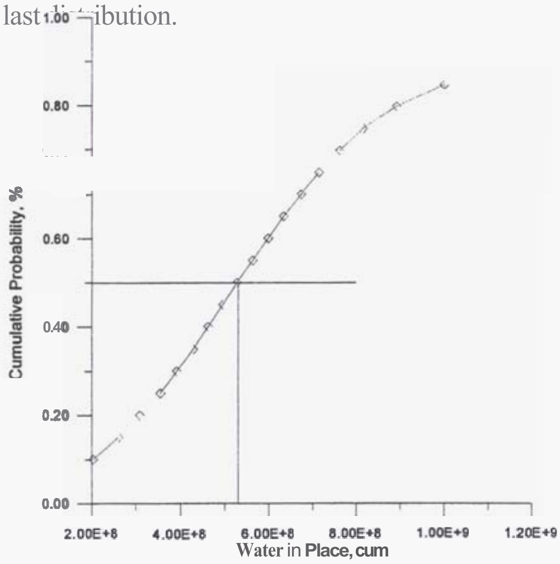

Figure 2. Distribution of water in-place computed by "variable arguments for distribution function".

4. PERFORMANCE ESTIMATIONS

As the exploitation proceeds, sufficient field performance data become available and, thus, the geology based volumetric reserve estimations can be compared against the decline curve trends. Subsequently, the field pressure behavior enables one to apply the material balance technique. The reliability of the resulting values would increase as this sequence of computations is repeated at every step.

4.1. Decline Curve Analysis Method

The decline curve analysis *(Arps,* 1970) is a basic tool for estimating the remaining reserves by extrapolating the performance trend to a limiting value. This analysis technique can be applied if there is enough performance history to form a continuous trend of the performance variable, which is a function of an independent variable that could be either cumulative production or time. A varying characteristic of the reservoir performance (here the reservoir pressure) is then chosen as dependent (or performance) variable to generate a trend curve. For extrapolation purposes this variable must meet two requirements : (1) it must change in a uniform manner, (2) it must have a known end point. Thus, the reservoir pressure (the dependent variable) must have an end point, of which its location is defined by the independent variable (here the temperature). For instance, a pressure end point of approximately 20 bars is chosen for the temperature of 2**10°C,** at which all water would have been withdrawn from the reservoir and only steam would have remained in the pore volume upon complete depletion. Therefore, at the reservoir temperature of 210°C the steam becomes saturated at the correspondent pressure of 20 bars.

The pressure values of a well, assumed to be representing the average reservoir pressure throughout the production history, were used as the dependent variable. Figure 3 shows a semi-log plot of pressure vs. time with exponential fit. Besides that the cumulative production data is adjusted by taking the amount of recharge incurred during exploitation into account. Figure 4 illustrates the pressure versus cumulative production behavior with linear fit. The pressure end point of 20 bars in Figure 4 indicates an ultimate recovery of 300 million cubic meters of water. The remaining 2.5 million cubic meters of water equivalent steam in the reservoir would be insignificant.

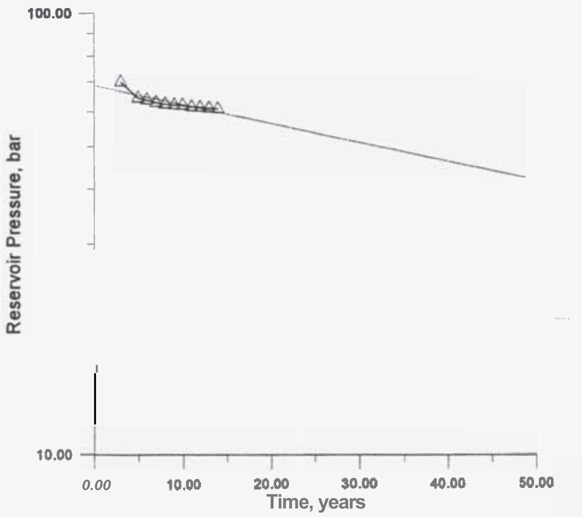

Figure 3. Pressure change with time.

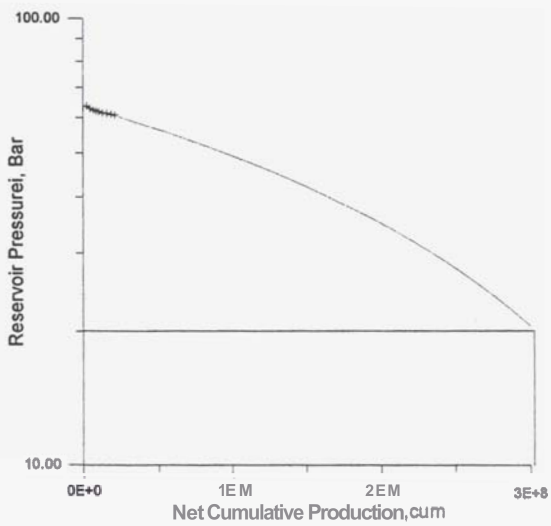

Figure 4. Pressure change with net cumulative production.

4.2. Material Balance Method

The material balance technique, which utilizes the Law of Conservation of Matter, is an invaluable tool for direct calculation of reserves volumetrically. Ugur (1996) used the material balance method for determining the volume of water-in-place in Kizildere geothermal reservoir and found a value of 603×10^6 m^3.

The above study was carried out using the data of well KD-7, assuming that its pressure represented the average reservoir pressure. A stochastic approach was attempted in the application of the material balance method. Additionally, the distributions of two-phase compressibility, pressure drop, and water density were generated from data of several wells. The result of the stochastic study is shown in Figure 5. An expected value of water in-place is found to be 786 million cubic meters of water from the mean value of the distribution.

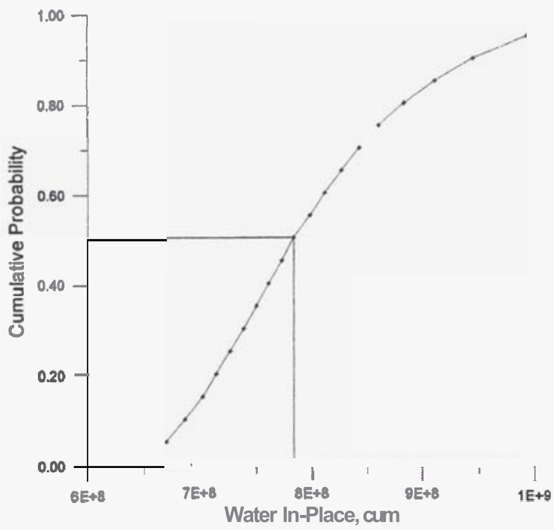

Figure 5. Results of material balance method using stochastic approach.

4.3. Reservoir Limit Tests

The result of a long-term production test was illustrated in Figure 6. Analysis of this test resulted in a initial reserve (initial pore) volume of 535×10^6 m^3, a reasonable value that confirms the findings of other studies (Dominco, 1970 and Ugur, 1996). Figure 7 shows a Cartesian plot of an interference test, which indicates a reservoir drainage area of 3.45 km^2 for a constant pay thickness. This figure is in reasonable agreement with the drainage area of 2.85 km^2 estimated using the geological and geophysical information by Dominco (1970).

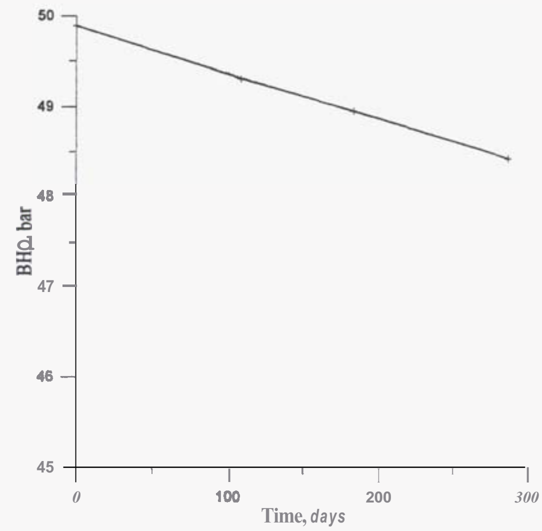

Figure 6. Plot of long term production test.

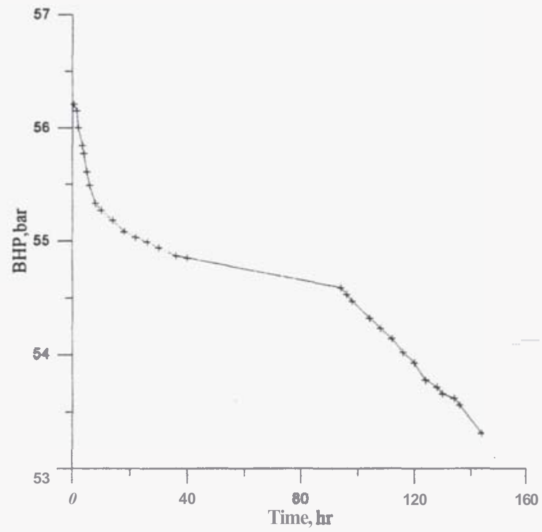

Figure 7. Plot of interference test.

5. SIMULATION STUDIES

Reservoir simulation is a very useful tool for studying reservoir behavior to estimate reserves. Simulation studies for estimating the water in-place was carried out on a previously developed lumped parameter model (Alkan et al., 1990). Several simulation runs were performed in order to match the production history. Due to some erratic initial production performance the early time matching is somewhat unsatisfactory, as seen Figure 8. Simulator input data was chosen from the recent work (Serpen et al., 1995, Serpen et al., 1998). The obtained results provided us with the estimation of reservoir volume of $490x10^6$ m^3 of water.

The cumulative water influx (recharge) computed by simulation study confirms the calculated recharge from the known rate of 550 ton/h.

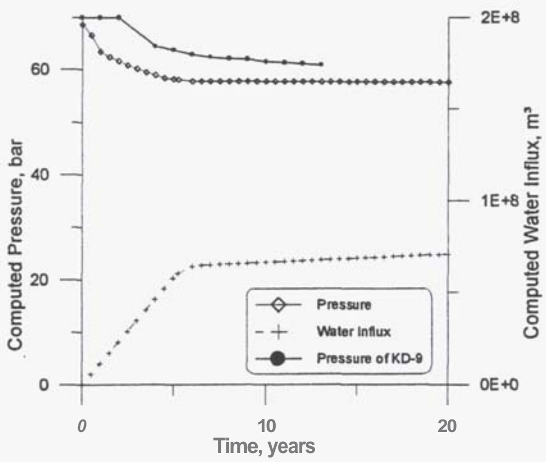

Figure 8. Model results and measured values.

The time of formation of *two* fluid phases in the reservoir is obtained from the simulation and is confirmed with the field observations. However, as noted previously, the pressure decline obtained by simulation differs slightly from the observed pressure data, mainly because the early rates of production were small and fluctuating.

6. DISCUSSION OF RESULTS

In this study, both deterministic and stochastic approaches were used in conjunction with the different methods of reserve estimates. The stochastic approach was utilized when the uncertainties were present in geological and engineering data. With the exception of decline curve analysis and stochastic evaluation of material balance, all resulting values obtained by different methods can be considered in close agreement with each other for engineering purposes. It is widely known that the decline curve analysis results in rather conservative values. On the other hand, if the performance analysis points out a lower water in-place value than the volumetric calculation indicates, this might imply that the production practices should be re-evaluated (Arps, 1970). For instance, the production rate is possibly rather low, and more drainage points are needed.

Finally, a probabilistic evaluation is conducted by taking all obtained and previously available reserve values into account. The Bernoulli distribution was the probabilistic evaluation method chosen to fit the data. The mean value of the fit resulted in a reserve value of $525x10^6$ m^3.

7. CONCLUSIONS

This study has shown that reserve estimation methods of petroleum engineering can be utilized for the same purpose in geothermal engineering. A mean estimate of water in-place for Kizildere geothermal reservoir was found as $525x10^6$ m^3.

8. ACKNOWLEDGMENTS

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