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ACCOUNTING FOR THE EFFECT OF TDS AND NCG ON SALTON SEA RESERVOIR RESPONSE

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ABSTRACT

The Salton Sea reservoir, located in Imperial County, Ca., is unique in several ways from most liquid-dominated geothermal reservoirs that have been developed to date. One of these differences is the presence of hyper-saline brines containing up to 28% TDS (Total Dissolved Solids) and up to 0.2% NCG (Non-Condensible Gas).

A simple material and energy balance model has been developed to study the effect of TDS and NCG on Salton Sea reservoir response. This study demonstrated that during the development of a two-phase system the partitioning of the NCG into the vapor phase and the consequential concentration of the TDS in the brine drastically alters the reservoir fluid properties. In modeling pressure depletion of hyper-saline reservoirs, such as the Salton Sea, these changes in reservoir fluid composition were shown to seriously affect the simulation results.

As a result of these findings, a compositional fluid property package was developed using published data on H_2O-CO_2-NaCl mixtures. This fluid property package was then incorporated into the simulation program used by Unocal. Validation of the fluid property package in this simulation program was made using measured reservoir temperature, surface enthalpy, and surface flash data.

The development of a compositional simulation program for geothermal applications has advanced our ability to study depletion mechanisms that are sensitive to compositional changes. This program is currently being used to study the effect of injection and steam cap development on long term operations and to develop a field model of the Salton Sea reservoir.

INTRODUCTION

The fluid contained in geothermal reservoirs is a mixture of a multitude of chemicals. Components present in reservoir brine other than water are normally grouped into two categories, namely non-condensable gas (NCG) and total dissolved solids (TDS). For hyper-saline brines, such as the Salton Sea reservoir brine, the total dissolved solids group is comprised mainly of salts with NaCl being the most abundant species. Non-Condensible gas contained in the Salton Sea brine is primarily CO_2.

Early modeling of geothermal reservoirs was based on simulation programs using pure water properties. The level of inaccuracy in modeling geothermal reservoirs containing hyper-saline brines using pure water fluid properties has been a topic of discussion for some time. To our knowledge no one has determined magnitude of error on calculating reservoir response if TDS and NCG levels observed at the Salton Sea are not included in the simulation program.

To determine the magnitude of error on reservoir response calculations introduced by use of pure water fluid properties a simple material and energy balance model was developed. In this model the fluid properties are calculated using a PVT package capable of handling pure water and H_2O-CO_2-NaCl mixtures. The non-condensible gas and salts present in the reservoir fluid at the Salton Sea are believed to behave in a similar manner as the CO_2 and NaCl present in this model.

SINGLE BLOCK MODEL

Many methods have been developed over the years to estimate the recovery from oil & gas reservoirs. Material balance type methods, such as those developed by Muskat and by Tarner (Craft and Hawkins, 1959), can be powerful tools in predicting overall performance of volumetric (*i.e.*, solution gas drive) oil reservoirs. Since the production mechanism of liquid dominated geothermal reservoirs is similar to a solution gas drive, these material balance type of methods should also be applicable to geothermal reservoirs. An important addition to these types of calculations required for geothermal reservoir performance predictions is the addition of energy balance terms to the overall mass balance equations.

To study the effect of brine composition on overall recovery from a geothermal reservoir, a single block material & energy balance model was developed using FORTRAN coding. In this model, TDS is modeled as pure NaCl and NCG is modeled as pure CO_2. Fluids are produced from this block in a step wise manner similar to Muskat's method.

This step wise integration of the depletion process can be best explained by referring to a physical model shown in *Figure 1* below:

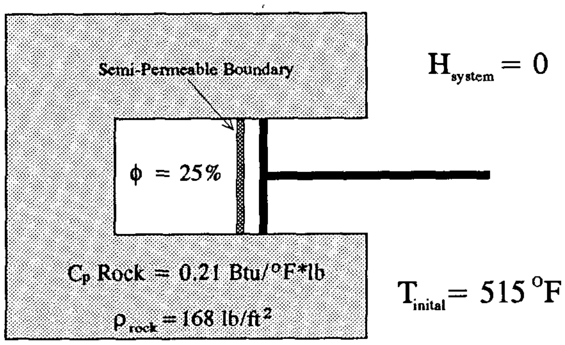

Figure 1. Single block geothermal reservoir model

On each integration step the pressure in the block is reduced by pulling the piston shown in *Figure 1* back. The fluid is then allowed to expand into the space between the semi-permeable boundary and the piston. The ratio of liquid to vapor that flows into this space is based on relative permeability data that was assigned to this semi-permeable boundary, as shown in *Figure 2* below:

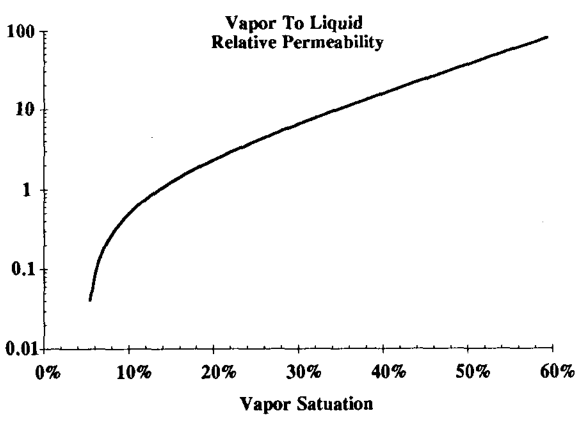

Figure 2. Relative permeability data assigned to the semi-permeable boundary used in the model.

After the system has come to thermal and pressure equilibrium, the volume of fluid between the piston and the semi-permeable boundary is produced by slowly moving the piston back to its original position while the fluid is bled off at a constant pressure.

The produced liquid is then flashed down to 100 psig. The resulting steam from these flash calculations is added to the steam contained in the produced vapor. The total steam produced is then divided by the original mass in place to yield a recovery factor. These step wise depletion steps are carried out until a desired recovery or lower reservoir pressure limit is reached.

MODEL RESULTS

Reservoir simulation runs, using the model discussed above, where made for a reservoir containing pure water, containing brine of a composition typical of the Salton Sea Field, and containing brine with a trace of NCG. A plot of reservoir pressure *v.s.* recovery factor for these three reservoir fluids is shown in *Figure 3* below:

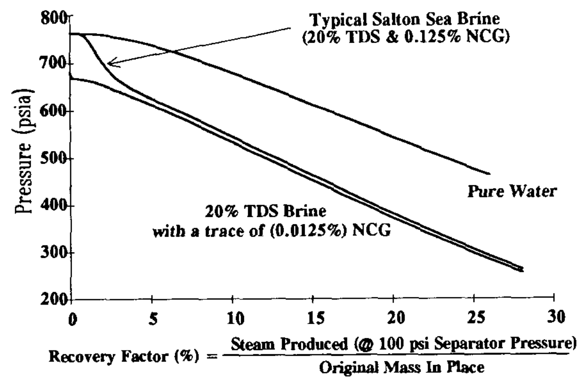

Figure 3. Reservoir Pressure v.s. Recovery Factor

The effects on the bubble point pressure resulting from the NCG and TDS contained in the brine found at the Salton Sea Field tend to cancel each other out and thereby result in a bubble point pressure that is close to that of pure water. With essentially the same bubble point pressure the recovery curves for pure water and for Salton Sea brine are similar to each other at recoveries below 1%.

As the reservoir is depleted, and the vapor saturation increases, most of the CO_2 in the Salton Sea brine partitions into the vapor phase. This loss of CO_2 from the liquid phase results in a rapid pressure depletion as shown in *Figure 3* above. By the time 4% recovery is reached, the pressure depletion levels off and begins to follow the curve for brine containing only a trace of CO_2.

As depletion continues, partitioning of the CO_2 from the liquid phase into the vapor phase results in high levels of CO_2 in the vapor phase. Above the critical vapor saturation, this vapor phase becomes mobile and the concentration of CO_2 in the produced 100 psi steam quickly rises as shown in *Figure 4* below:

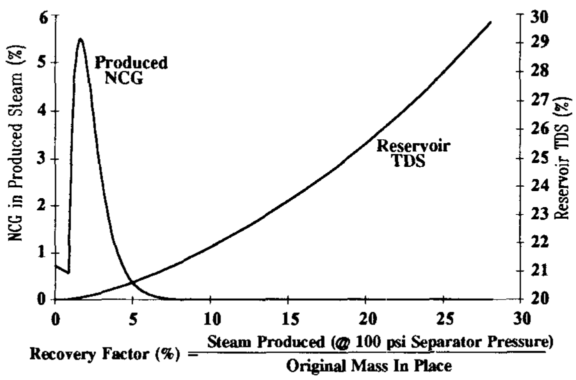

Figure 4. Produced NCG & Reservoir TDS as a function of Recovery Factor.

As depletion progresses, the CO_2 is swept out of the reservoir and the concentration the CO_2 in the steam drops. Later in the production life of a geothermal field flashing of the less mobile liquid phase results in concentration of the brine. This brine concentration process could result in high reservoir TDS values as shown in *Figure 4* above .

PVT MODEL FOR GEOTHERMAL FLUIDS

As a result of these findings a compositional fluid properties package (*i.e.*, PVT model) for geothermal fluids was developed using literature data on H_2O-CO_2-NaCl mixtures (Anderson and Probst, 1992). This package is similar to the package used in the single block model discussed previously but is capable of estimating properties over a much wider range of pressure, temperature and compositions required in reservoir simulations. This fluid property package was then incorporated into the simulation program used by Unocal.

The assumption that the fluid properties package in this simulation program, which models the reservoir brine as a mixture of H_2O-CO_2-NaCl, accurately matches the complex brine mixture at the Salton Sea was then tested. Using this program, production enthalpy and surface flash predictions were made for an average brine composition and average production interval temperature observed at the Salton Sea. These results agreed closely with observed separator enthalpy and flash data.

An experimental program is currently underway to obtain fluid property data on actual geothermal brines. Results from this program will then be used to fine tune the fluid properties package for the Salton Sea.

CONCLUSIONS

The presence of TDS & NCG in hyper-saline geothermal reservoirs exerts a strong influence on the recovery performance. For the same recovery factor, a reservoir containing brine of a composition typical of the Salton Sea reservoir will experience about twice the pressure depletion as compared to a reservoir containing pure water. Partitioning of the NCG into the vapor phase and brine concentration effects are important to consider.

Development of a compositional reservoir simulation program, which models hyper-saline geothermal reservoir brine properties as H_2O-CO_2-NaCl, has advanced our ability to study reservoir depletion mechanisms that are sensitive to compositional changes. From these studies improved reservoir performance predictions and reserves estimations can be made.

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