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Decision Analysis Applied to Las Tres Vírgenes Geothermal Field Mexico

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ABSTRACT

"The Tres Vírgenes geothermal field in Baja California State, in Mexico, is located in the Santa Rosalia Basin. This geothermal system is related to a quaternary volcanic complex, composed of three volcanoes, the reservoir is a liquid-dominated type. The reservoir is highly influenced by fractures rocks and storage fluid at high temperature, exploration began in 1983 by Comision Federal de Electricidad. In 1997 the first stage of "Las Tres Vírgenes" geothermal project was initiated with two 5 MW units, increasing to four the number of geothermal fields in development in Mexico. Up to the present, nine wells have been drilled, six are producers and three are reinjectors, with depths ranging between 1290 and 2500 m. The water produced by the wells has a sodium-chloride composition; characteristics of geothermal brine completely equilibrate at a temperature estimated at 280 ºC. The main problem occurring in the production wells is the scaling and plugging in pipes and reservoir feed zones as consequence of silica and calcite, which has caused a high and fast decline in well production. CFE has employed acidizing methods to improve the production characteristics of some wells. A statistical method named "decision analysis" was applied to select the best options related to the future new well production estimated under all possible scenarios.

1. INTRODUCTION

"Las Tres Vírgenes" geothermal field is located in the eastern coast of the Baja California Peninsula, 35 km NW of Santa Rosalia city (Fig.1). The Comision Federal de Electricidad (CFE) started geothermal exploration activities there in 1982, with geophysical, geological and geochemical feasibility studies (e.g. Ballina and Herrera; 1984; Lira et al., 1984; Quijano, 1984; Tello, 1988; Gutiérrez-Negrín, 1990; Viggiano, 1992; López-Hernández et al., 1995; Tello, 1997). Such studies supported the decision of drilling in 1998 the first exploratory well named LV-2 (Lopez, 1998). To achieve a better knowledge of the natural state of the geothermal system subsequent studies were done (Tello, 1998; Vargas and Garduno, 1988; Bigurra, 1989; Lopez et al., 1989). At a second stage, studies of the structural geology of the hydrothermal system were carried out to optimize the locations of the new perforation wells (Tovar, 1989; Gutierrez, 1990, Viggiano, 1992; Garcia y Gonzalez, 1998).

A lot of the time, the reservoir engineer assumes through calculation that all replacement wells will be producing the same flow rate (initial production parameter). However this is an assumption only, to minimize the calculation, but in fact the wells do not produce the same fluid flow rate, because the reservoir conditions are not isotropic, therefore the number of replacement wells have to include the probably (possibility) of drilling wells with low or zero production. As a consequence, the reservoir exploitation feasibility studies should consider drilling a greater number of replacement wells than the results of theoretical estimation; since it causes an equilibration or compensation between good and bad production wells. The difference between theoretical and true number of wells will be added to the expected cost of the project.

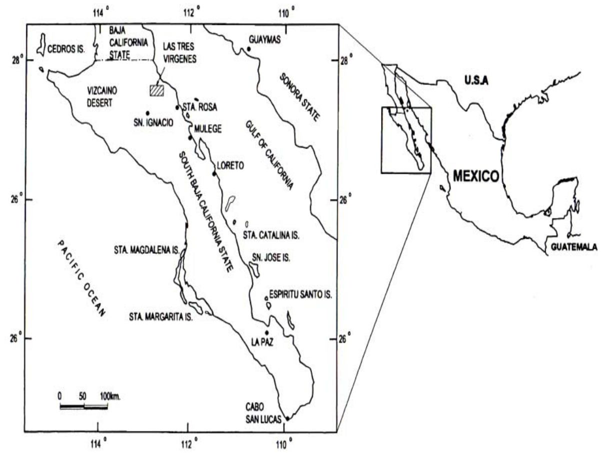

Figure 1: Las Tres Vírgenes geothermal field

2. OBJECTIVES

The main objective of this paper is to apply the decision analysis method to drill a new well in Las Tres Vírgenes Reservoir, from the condition found during drilling and production stages in wells located in this reservoir.

3. GEOLOGICAL SETTING

Within a regional context, the geothermal system of LTV is located in a Plio-Quaternary depression of NW-SE trend, the Santa Rosalía basin which constitutes the western limit of a deformation zone related to the Gulf of California opening (Demant, 1981; López-Hernández et al., 1995). The western border of the basin is occupied by a faults system trending NW-SE. Gutierrez-Negrín (1990) and Viggiano (1992) established that "Las Tres Virgenes" is located in an active tectonically area associated with the faulting process of the Gulf of California opening. Three Quaternary volcanic centers (from oldest to the youngest): La Reforma caldera, the Sierra Aguajito and Las Tres Vírgenes complex were identified. The chemical compositions of these volcanic complexes are characterized by calco-alkaline series, excepting an alkaline rich pyroclastic flow and some basaltic cones observed at La Reforma, which are of peralkaline type (Sawlan, 1986). The most active thermal zone has been located in the northern limit of the youngest volcanic center whose age is around 0.44 Ma. This complex comprises of three volcanoes: La Virgen, El Azufre and El Viejo. In the north zone of *Las Tres Vírgenes* complex a chemical composition of dacitic type was observed. The south zone shows a different chemical composition covering a range from basaltic to rhyolitic products. Regional and local geological maps of the Las Tres Virgenes geothermal system had already been published (López-Hernández et al., 1995). A complete compilation of the main geological and geophysical features of "Las Tres Virgenes" geothermal field is also reported by López-Hernández et al. (1995). The geothermal field's heat source appears to be related to the magma chamber of the La Virgen volcano.

4. PRODUCTION AND GENERATING HISTORY

To the present day, 9 wells have been drilled, 6 are producer and 3 are reinjectors (Quijano et al. 2003). Figure 2 presents a simplified geological map showing the location of the wells drilled in "*Las Tres Vírgenes"* geothermal field.

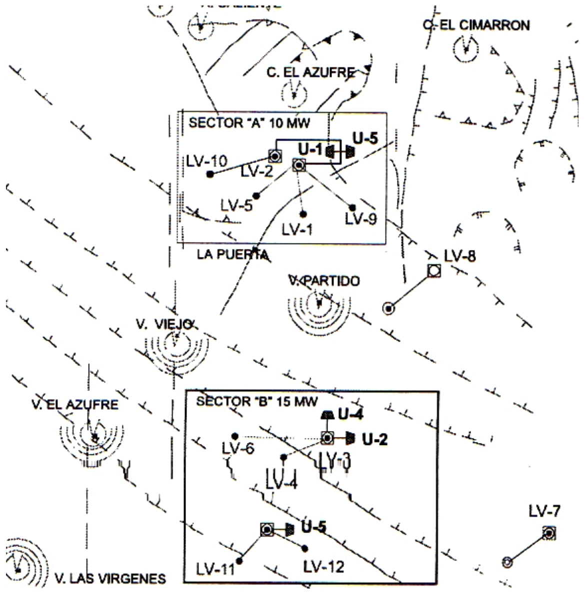

Figure 2: Las Tres Vírgenes geothermal wells

By July 2001, the first power units, two 5-MW condensing turbines, were installed at "*Las Tres Vírgenes*". Steam production during 2002 was 0.28 millions metric tons, at an average annual rate of 37 t/h. On average during the 2003 year, three production and two injection wells were in operation. Only one power unit operated between January and the first days of November, with a total generation of 19 GWh. Electricity produced at the field was distributed to nearby towns which are isolated from Mexico's national electrical grid (Residencia de "*Las Tres Virgenes"*, 2003). The steam is supplied by four wells located near the power plant. The wellhead pressure is 5-8 bars, as the steam flow rate is 15-30 t/h. The following data summaries the well conditions:

Well LV-1, reached downhole temperatures of 275 °C at 1100 m of depth, it is locate in same platform of well LV-5. It produced 25 t/h of steam flow rate before scaling and plugging problems. The total depth reached during drilling was 1887 m.

Well LV-2, drilled in 1986, reached downhole temperatures about 200 °C at 380 m depth, it was not a production well.

Well LV-3, drilled in 1994, was the first productive well in Tres Vírgenes geothermal field, increasing the expectation of obtaining sufficient production for commercial generation. It well reached a total depth of 2150 m, it produced 25 t/h of steam flow rate and 50 t/h of brine flow rate. It developed serious calcite scaling problems during 2000 (Armenta et al., 2001).

Well LV-4, reached downhole temperatures of 275 °C at 1500 m depth, this well has been producing 30 t/h of steam flow rate, the total depth reached during drilling was 2500 m.

Well LV-5, has a total depth of 1859 m, the well reached temperatures of 200 °C downhole. It has been producing.

Well LV-7, reached a total depth of 2000 m, with downhole temperatures of 200 °C, has been using for reinjection.

Well LV-8, reached 1600 m of total depth, the downhole temperature measured was higher than 225°C, has been a production well.

Well LV-11, drilled in 2000, it reached 250 °C downhole temperature at depth of 2000 m. The well has been producing 25 t/h of steam and 50 t/h of brine at 5 5.5 bara wellhead pressure during 2001 (Gutierrez et al., 2001). During drilling activities the total drilling mud lost was calculated as 4000 m^3.

Well LV-13, drilled in 2000-2001, it has been producing, it reached 250 °C downhole temperatures at depth of 2000 m.

5. DECISION MODELS

A decision may be defined as the process of choosing a solution to a problem, given that at least two alternative solutions exist. It is obvious that before a decision can be made, several steps must be carried out. These steps may be summarized as follow.

1. Decision Maker (DM) becomes aware of existence of problems.
2. DM gathers data on the problems.
3. DM develops a model that describes the problems.
4. DM uses a model to generate alternative solutions to the problems.
5. DM chooses from alternative solutions.

The five-step decision-making process can be related to the first three steps as follows:

1. Problem recognition, observation, and formulation.
2. Model construction
3. Solution generation

5.1 Types of Decisions

There are essentially three major types of decisions.

1. Decisions under certainty.
2. Decisions where prior data can be used to compute probabilities to use in making decisions.
3. Decisions where prior data exist for computing probabilities.

The conditions under which each type occurs are the followings:

5.1.1. Decision Making Under Certainty

Whenever there exists only one outcome for a decision, we are making decisions under certainty.

5.1.2. Decision Making Using Prior Data

Whenever a decision must be made on a repeated basis with multiple outcomes being possible, and the circumstances surrounding the decision are always the same, we have what may be called a decision using prior data. Since it is possible to use past experience to develop probabilities that each outcome will occur, this type of decision making uses probability-based decision-making models.

There are there conditions necessary for this type of decision making:

1. Decisions are made under the same conditions.

2. There exists more than one outcome for each decision.

3. There exists previous experience that can be used to derive probabilities for each outcome.

If any one of these conditions does not hold, then it is not considered to be a decision based on prior data.

5.1.3. Decision Making Without Prior Data

In cases where a decision is not made repeatedly or there is no past experience to use in computing probabilities or the circumstances surrounding the decision change from instance to instance, we consider the decision to be made without prior data. It is so termed because the same decision will only be made once, and as such, no past experience is available to help in the decision-making process.

For these types of the decision problem, we can take one of two approaches. We can use only the outcomes for each decision to determinate the decision that best fits our view of the external factors surrounding the problem On the other hand, we many choose to use subjective estimates (not based on prior data) known as subjective probabilities to determinate a decision.

6. TERMINOLOGY OF DECISION-MAKING MODELS

As with any type of model, decision-making models have a terminology of their own. This terminology describes the three parts of a decision:

1. The alternative decisions from which the DM may choose.

2. The states-of-nature, or external actions facing the decision maker.

3. The outcome resulting from the use of a given alternative when a certain state-of-nature occurs.

1. Alternative Decisions

When a DM is faced with a problem requiring a decision, one of the first actions he must take before actually arriving at a decision is to determinate the alternatives upon which the final decision must be based.

2. The States-of-Nature

A decision maker is faced with a decision situation where multiple outcomes result for a given strategy is facing multiple states-of-nature, or external actions. States-of-nature are the circumstances that affect the outcome of the decision but are beyond the control of the DM. They are also referred to as external actions because they are situations that are external to the DM.

3. Outcomes

For each combination of a strategy and a state-of-nature there will exist an outcome. This outcome may be expressed in terms of profits, it may be expressed in the terms of present values (as was the location decision), or it may be expressed in terms of some *nonmonetary* measure.

To determinate the outcomes, it is necessary to look at all possible combinations of alternative decisions and states-of-nature to determinate the outcome that would result if given alternative were employed and a particular state-of-nature occurred.

Decision Trees

A clear, easy way to structure the decision-making process is through a decision tree. The decision tree is made up of action nodes, and branches. In the decision trees, action nodes will be denoted by a square and will represent places in the decision-making process where some state-of-nature will occur. The branches are used to denote the decisions or the states-of-nature. Probabilities can also be placed on the branches to denote the probability of a given state-of-nature occurring. Finally, payoffs are placed on the end of the final state-of-nature branches to show the result of making a particular decision and then having that particular state-of-nature occur.

7. DECISION MAKING WITHOUT PRIOR DATA

It is not possible to say that one of these models is any more correct than another. The appropriateness of the each model depends upon the outlook of the DM and whether or not the DM wishes to use subjective probabilities.

7.1. Pessimist's Decision Model

The decision maker who is pessimistic about the states-of nature or who feels, because of economic insecurity, that high losses must be avoided at the risk of losing possibly high profits, will lean toward using the decision model known as the *pessimist's decision model.* The major concept of loss avoidance, we determine the lowest outcome for each strategy and then select the strategy having the highest of these lowest outcomes. Since we are maximizing the minimum outcomes, this decision model is also known as the maximin criterion. The procedure may be described as follows:

Step 1: For each alternative, determinate the lowest-valued outcome and record this in a list.

Step 2: From the list of outcome, choose the maximum value. The alternative associated with this maximum outcome is the strategy to employ.

8. DECISION ANALYSIS ON TRES VIRGENES GEOTHERMAL FIELD

The production wells in Las Tres Vírgenes geothermal field have been flow tested several times, and showed some variations in their total production, discharge enthalpy and wellhead pressure (Garcia et al., 2000). Besides, the problems like mud drilling losses and carbonate scaling do not let us know the real delivery conditions existing in each well (Ocampo et al., 2004). Since 6 out of 9 wells drilled have been producers in Las Tres Vírgenes, it is possible to assume values of p=0.66 (66 %) for the probability to get a high production in a new well and q=0.44 (44 %) for the probability to get a low production in new wells drilled. This can be represented through a decision tree as shown in Figure 3. It is evident that finding a new well location from geophysical surveys in this reservoir could be advantageous from the viewpoint of production, although at an increase to the project cost -- therefore we considered a probability of p=0.70 of getting good results of the geophysical measurements and q=30 % of getting low results. Figure 3 shows the decision tree done with these probability values, so we can observe the different scenarios resulting from this figure.

1.- Low risk production conditions.

2.- Medium risk production conditions.

3.- High risk production conditions.

9. CONCLUDING REMARKS

"Las Tres Vírgenes" geothermal project began in the 1980s and the first exploratory wells drilled in 1986 (LV-2), after 18 year of development of the field, at the present day there are nine drilled wells, six of which are producer and three of which are reinjectors. The information obtained during this development stage of the field leads to knowledge that the reservoir is hosted in a fractured system within the granite, heated by a magma chamber associated with the proximity of the Las Tres Vírgenes volcanic complex. The reservoir is liquid-dominated and includes an area of 90 km^2. The reservoir is considered to have a thickness of 1500 m, based on the interpretation and characterization of the production zones. The permeability of the system is of a secondary type, almost all wells drilled in this reservoir have registered high viscous mud losses, which have caused damage in the production formation (skin damage), mainly in the permeable feeding zones. An additional and important problem has been seen during production due to calcite deposition and scaling both inside the pipe and possibly also in the reservoir zones near to the wells feed layers.

The steam is supplied by four wells located near the power plant. The wellhead pressure is 5-8 bars, and the steam flow rate is 15-30 t/h. Decision analysis has been applied using a decision tree, revealing three possible alternatives, according to the reservoir information obtained from the nine wells drilled so far, the best option before drilling new wells is to conduct a geophysical survey to minimize the risk of drilling a well with low or zero production.

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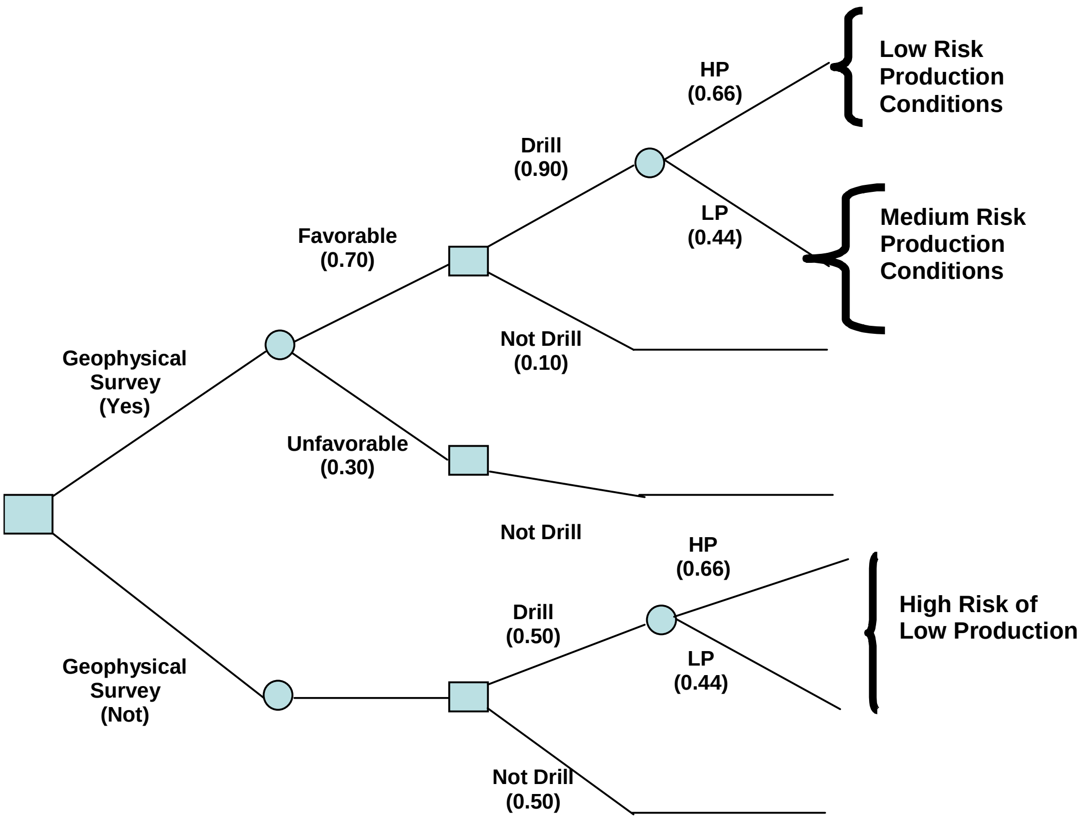

Figure 3.- Decision Tree of Las Tres Vírgenes geothermal wells