ECONOMIC EVALUATION OF ALTERNATIVE STRATEGIES OF GEOTHERMAL EXPLOITATION

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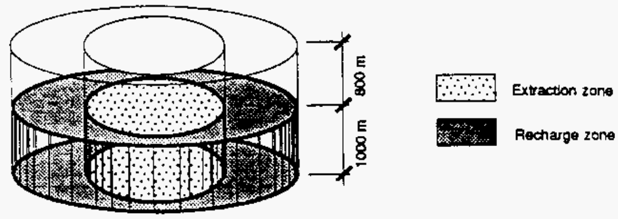
ABSTRACT

The mathematical models of geothermal reservoirs may predict with fair approximation the actual hehaviour of the fields. making it possihle to simulate the response of the reservoir undrr different exploitation strategies. Matching the behaviour of the field with the energy generated hy alternative sizes of the installed power plant, the economic effects of the alternatives have been calculated. The results show that the generally adopted criterion of installing the capacity which guarantees a continuous maximum load for the technical life of the plant is not necessarily the best one from the economic standpoint. In the simulated case. the maximum continuous load for 25 years is Y0 MW, hut the minimum actualized production cost is achieved with a plant of 110_120 MW and the maximum total benefit with a plant of 150 MW. In these cases a decline of production with respect to the nominal installed capacity is predicted during the life of the power plant.



	SURFACE (km^2)	THICKNESS (m)	T (°C)	P at 1400m (bar)	Perm. (mD)	Poros. (%)
Extraction zone	5	1000	250	85	50	5
Recharge zone	20	1000	250 - 150	85	50	5

Figure 1 - Assumed Reservoir Parameters

1. INTRODUCTION

Geothermal resources constitute a form or energy that. at least in the short term (that is over hundreds of years), can he classified as not renewable. This makes their exploitation especially critical. inasmuch as decisions on the rate and mode of fluids extraction are to a large extent irreversible and can lead to important economic losses.

Recent advances in the field of reservoir engineering have provided a powerful tool in this context. In fact. the possibility of predicting the evolution of the reservoir performance undrr different schemes of exploitation allows to estimate the benefits originated from electric energy generation and to compare them with the relevant costs. Obviously, such comparison is bound to he associated with a margin of uncertainty, whose degree depends on the actual knowledge of the characteristic parameters of the reservoir and on the validity of the assumptions on the energy value.

At any rate, it is felt that. regardless of the level of knowledge achieved. this assessment may provide useful guidelines for a proper selection among different exploitation alternatives. to he made at the end of the feasibility study or even during the exploitation stage.

The present paper aims to provide a methodological approach for the economic evaluation of alternative strategies of exploitation of a high-enthalpy geothermal field, on the hasis of thr predicted evolution of the reservoir. In order to offer a clearly understandable view of the involved problematics, simplified conditions have heen assumed in terms of reservoir characteristics, extraction procedure. generation options and investment-operation costs, as detailed in the next section.

2. ASSUMED PARAMETERS

2.1 Reservoir Characteristics and Extraction Procedure

The assumed characteristics of the reservoir are summarized in Figure 1. It can he noticed that the reservoir is hypothesized as a cylinder with a 5 km3 volume. surrounded by a cylindrical crown acting as a recharge sector. where temperature decreases moving outwards from 250 to 150°C and permeability remains constant.

The geothermal tluids are extracted from a depth of 1 400 m hy wells with a production casing diameter of Y 5/8", evenly distihuted throughout the extraction zone. The average capacity of the wells. in the initial phase of operatinn. is taken at around 5 MW with a well head pressure of 8 har ahs. assuming a steam specific consumption of 8 kg/kWh. Residual tluids are reinjected in a strip located at the outer margins of the recharge zone.

2.2 Generation Options

The installed capacity is surely the most crucial parameter for the definition of the exploitation strategy. governing to a large degree all the generation capability.

Several factors. besides the actual potential of the reservoir. play an important role in the selection of the capacity to he installed. In fact. the exploitation policy can he more or less conservative, depending on the field/power plant ownership set up, the energy market conditions, the existence of viable alternative generation sources. the risk analysis with respect to the field evolution. the scale factor in the investment costs, the availability of standard equipment.

In our hypothetical case. disregarding strictly local factors. alternative capacities ranging frum 80 to 200 MW have been examined.

2.3 Investment and Operating Costs

The assumed investment and operatinn & maintenance costs, expressed in US$, are summarized herebelow:

a. *Field Costs*

Exploration and infrastructures (actualized to the start of plant construction): 10 x 10^6

. Drilling of production wells (including share of reinjection wells and 25% negative wells): 1.7 x 10^6 each

Separation - conveyance system: 1.0 x 10^6 $ each production well

. Operation and maintenance: 2%/year of the investment cost

b. *Plant* **Costs**

. Plant and substation (including civil **works):** 1 000/kW

. Operation and maintenance: 2%/year of the investment **costs**

c. *Scale Factor*

10% decrease of unit cost for every doubling of the installed capacity (in excess of 50 MW)

Scale factor applies to the separation and conveyance system. to the plant and substation and to the operation and maintenance for both field and plant

d. *Disbursement Schedule*

Construction time: 3 years

. Disbursements: 20% the first year. 40% the second year. 40% the third year

3. EVOLUTION OF THE RESERVOIR UNDER ALTERNATIVE EXPLOITATION STRATEGIES

On the basis of the above specified assumptions, the behaviour of **the** reservoir under different exploitation schemes has been simulated utilizing numerical models.

The simulation shows that the reservoir remains in a liquid phase throughout its life, at least **at** the extraction level, and that depletion essentially takes place due to inflow of cooler water from the recharge **zone.** causing a decline in the enthalpy and pressure.

The *proven potential*, defined as the electrical capacity which can be maintained throughout the 25 years of useful life *of* the plant. **results** to be 90-95 MW. Drilling of new wells during the exploitation phase to make up for the reservoir decline proves to be effective only up to a certain limit, beyond which no significant improvement in the total **steam** production is **achieved** this limit corresponds to about 14 wells/km^2, that is to a distance among wells of 300 m.

The main findings of the simulation, referred to the field performance during 25 years of operation as a function of the installed capacity. can be summarized as follows:

<u>Evolution of Firm Capacity</u> (Figure **2)**

For **50** and **75** MW the nominal capacity is maintained until the end of the useful plant life, while for 100 MW. that is for **a** capacity slightly above the proven potential of the field, a limited decline starts to take place in the last 2 years. For higher capacities **a** sharp drop occurs well before the end of the plant useful life due to overexploitation of the field for the extreme case of 200 *MW*, **the** nominal capacity can **be** maintained for only **9** years and after 22 years there **is no** significant electrical generation.

<u>Number of Wells</u> (Figure 3)

The considered production wells include both the initial and the make-up **ones:** in the simulation program **a** threshold was set on the number of make-up wells, whereby no more drilling would take place once the capacity of the operating wells falls below around 2 *MW*. For installed capacities within the proven potential of the field. the rate of wells increase is regular and moderate. For capacities slightly above the proven potential, the rate of increase is initially moderate and abruptly turns to pronounced **as soon as** the inflow of cooler water becomes appreciable (after 20 years for 100 MW). For capacities well above the proven potential, the rate of increase is **very** high from the beginning of operation, until a time is reached when the addition **of** new **wells** does not bring on any significant benefit.

<u>Average Well Capacity</u> (Figure 4)

The evolution of the average well capacity is strictly related with the number of make-up wells needed to maintain the steam production. For **50** and **75** *MW* installed capacity the decline of the deliverability is gentle. from the initial **5.3***MW* down to the **final** 3-3.5 *MW*. **In** the other examined cases the trend becomes progressively more dramatic. to the point that for 200 *MW* the threshold of 2 MW is reached after only 11 years.

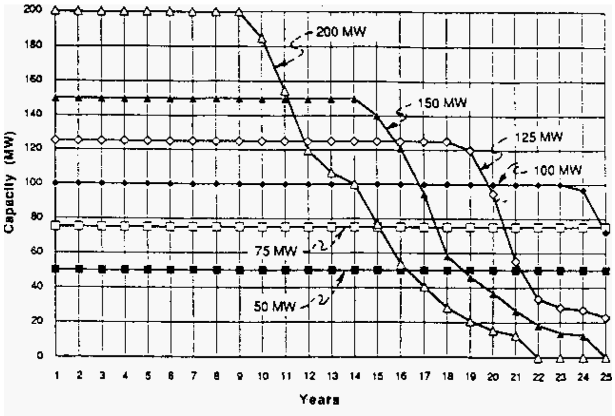


Figure 2 - Evolution of Firm Capacity with Time

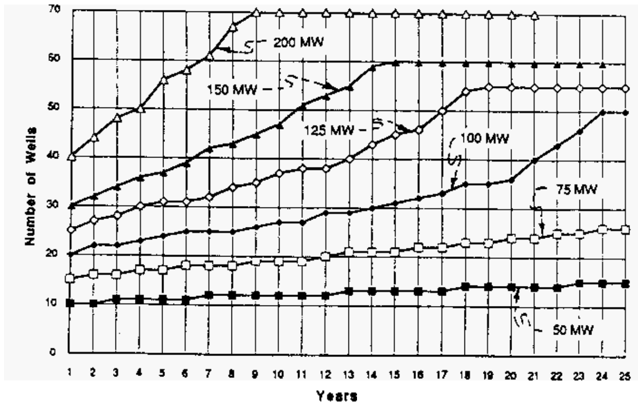


Figure **3** - Evolution of the Number *of* Wells with Time

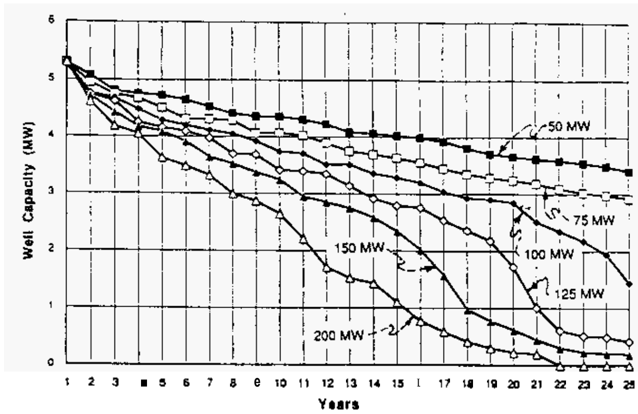


Figure **4** - Evolution of Average Well Capacity with Time

<u>Cumulative Energy Production</u> (Figure 5)

A linear relationship between the electric energy generation throughout the useful life of the plant and the installed capacity is observed until 100 *MW*, that is just above the proven potential of the field. After that, the rate of increase of generated energy becomes very low, so that a doubling of the installed capacity from **100** to 200 *MW* brings on an increase of energy of only 10%

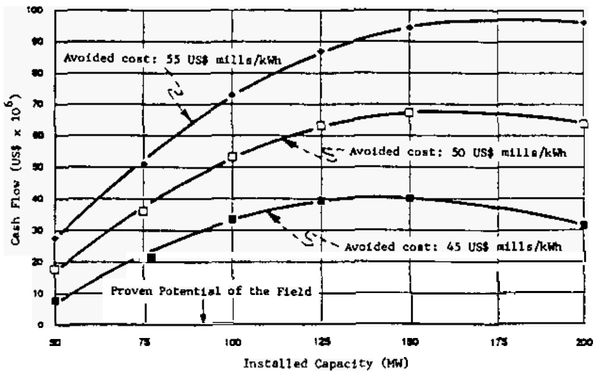


Figure 7 - Net Present Value of Total Cash **Flow** vs Installed Capacity

5. CONCLUSIONS

It is worth stressing that the **results** of this economic evaluation refer to a specific hypothetical case and therefore can not be uncritically generalized to different physical and economic situations. However. some interesting trends stand out from the study. which are expected to apply to **a** large extent to most development geothermal projects.

In the following comments reference is made to the proven potential of the field. defined as the capacity which *can* he safely installed and maintained during the **useful life** of the plant. In normal reservoir engineering practice **prudential** criteria are adopted in **the** determination of the proven potential. hy assuming reservoir parameters which are around the least favourahle level of the possible **range.**

The evaluation camed out over the hypothetical case shows that for the generation cost and even more for the cash fluw the best economic **results** are achieved **by** installing **a** plant whose capacity is from 10 to ***50%*** higher than the proven potential of the field.

This outcome contrasts with the usual policy of selecting **a plant** capacity equal or lower than the **proven** potential, with the aim to avoid the **risk** of having the plant operating at lower than nominal capacity during the last years of the exploitation phasc. Actually. at least in the simulated instance and presumably in the majority of the instances. it is economically advantageous to overdimension the plant to a degree to he established on a case-by-case basis for the following reasons:

. The most favourable economic conditions occur for capacities higher than the proven field potential.

The rate of economic deterioration heyond the optimum range is more pronounced in case of underdimensioning than of over-dimensioning.

. Considering the prudential approach adopted in determining the proven potential of the field. there is **a** good chance that the actual potential will **turn** out to he larger than the proven one: in view of this fact and of the rather limited economic losses associated with overdimensioning. **a** more aggressive development policy is deemed convenient under most situations.