A METHOD TO PREDICT PRODUCTION AND REINJECTION CAPACITY CHANGES USING LINKED WELLBORE AND RESERVOIR SIMULATORS

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Abstract

This paper describes a method to couple a wellbore simulator, a silica deposition simulator and a reservoir simulator. The method was designed to make use only of those variables in the three simulators which are common to the problem of estimating the variation of production and reinjection rates as the reservoir pressure and enthalpy changes. The obtained method resulted independent of the characteristics of each simulators and is readily applicable for any of the available simulation packages. The coupling control is carried out by an external program written in Visual Basic™ while the interchange of information is carried out by an Excel™ Sheet. Graphical presentations at the end of each time step are also carried out by the Excel Sheet. The method was tested utilising TOUGH2 (PC version) as the reservoir simulator, WellSim™ as the Wellbore Simulator and the SDRF as the Silica Deposition Rate Simulator.

1.0 INTRODUCTION

To forecast the response of a geothermal reservoir to exploitation is one of the most important steps of the studies done to define the technical and economical viability of building a geothermal power plant. The forecasting is aimed to define an exploitation scheme which is sustainable, environmentally friendly and at the same time is economically advantageous to the system or region. Taking into account the local and regional economics as well as fuel diversity and national strategy issues, an economically advantageous scheme will be that impacting the best the cost of generation and competing the best with other sources of generation. An environmentally friendly exploitation will be that minimizing gas emissions and that with adequate disposal of used fluids. A sustainable exploitation will be that in which the rate of mass and heat extraction from the reservoir is balanced by the rate of mass and heat recharge into the reservoir.

The recharge of mass and energy into the reservoir will have *two* sources; one will be of natural origin and the other will be represented by the reinjection, done in appropriate sites, of the separated water (in case of water dominated systems). The rate of mass and heat extraction from the reservoir will be governed by the pressure at which each of the wells of the steam system is set to operate and by the reservoir properties. In the case of water dominated reservoirs, this wellhead pressure will be determined by the separation pressure, the layout of the fluid conduction system and the scheme of power cycle being analysed. The well production rate at a given wellhead pressure (and its variation with time) are directly connected to the reservoir's pressure and enthalpy (and to the variation of these two parameters with time). As far as the variations of these two properties of the productive reservoir are kept at minimum (avoiding depletion), mass flow (and energy extraction) will be maintained. Declining of reservoir pressure is minimised by reinjecting the separated hot water. However, reservoir acceptance to reinjection will basically depend on the amount of water to be reinjected (governed itself by the separation pressure), its chemistry (governed by the chemistry of produced fluids), pressure and temperature on the reservoir pressure and on the permeability of the reinjecting formations. Chemistry and reinjection temperature will determine the rate at which the permeability of formations might decay mainly due to silica scaling.

Therefore reinjection temperature is also an important parameter in the analysis and will also depend **on** the scheme of the power cycle being analyzed. Consequently, for a given power cycle and given reservoir characteristics, the search for the best exploitation scheme will be focused in obtaining a separation pressure which makes the reservoir operation a sustainable and economical one. **Fig. 1** depicts a graphical representation of the integral reservoir analysis.

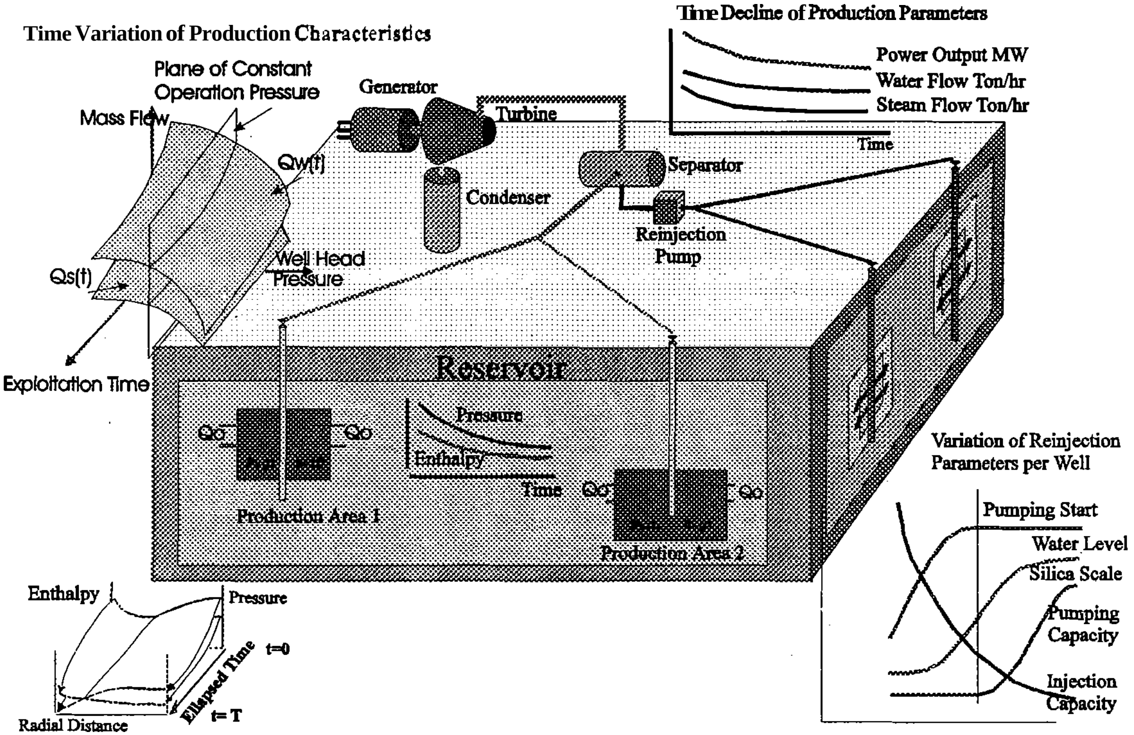


Fig. 1 Integral **Reservoir Analysis**

To do this analysis, it is necessary to forecast the variation of mass and energy extraction at constant wellhead pressure (to maintain the separation pressure constant) and of the injection capacity at constant injection temperature, during the operation life of the power facilities. Part of the analysis can be done using a well simulator, other part, using a reservoir simulator and other part using a silica scale simulator. In order to do an integral reservoir analysis, covering all the aspects explained above, the development **of** numerical tool which couples the capabilities of the three simulators was necessary.

To reach the objective **of** developing this tool with the least of programming effort, it was decided to externally link three of the commercially available packages, TOUGH2 (Pruess, 1991), WELLSIM^{TM} and SDRF (Itoi, **1994)** using the Object Programming and the Object Linking and Embedding capabilities of Visual Basic^{TM} and EXCEL^{TM}

2.0 THE PROCEDURE

The procedure is applicable to the forecasting stage of reservoir simulation. It is assumed that the reservoir model has been appropriately passed through a natural state and history matching calibration. It is also assumed that the candidate location **of** future possible production and reinjection targets have been defined by geological, geophysical and geochemical means.

To do the forecasting, a Visual Basic routine(GRASP; **Geothermal** Reservoir **with** Automatic Simulation of Production) was devised to control the whole simulation procedure, to serve as a communication means between the wellbore, silica deposition and reservoir simulators and to present to the user in "real time" the graphical results of the simulation process. The reservoir simulation process considers that the mass extraction and mass reinjection remain invariable during a time step. At the end of each time step, resulting pressure and enthalpy values of production and reinjection elements, are used to estimate new values for the mass (energy) extraction and reinjection (the latter will depend on the separation pressure of the power cycle being analysed). These new values are used as input data for the next time step of the simulation process. Requirements of additional production drilling are disclosed when the calculated mass and energy extracted from the reservoir prove insufficient to produce the steam necessary to run the power facilities at rated output. Additional reinjection drilling requirements are disclosed when progressively the existing wells turn incapable of accepting all the separated water. The procedure is repeated until the whole simulation time span has been covered (refer to Fig. 2).

With these results, the user can estimate the impact in the cost per installed KW and on the generation cost, and therefore to draw conclusions on the applicability of the analysed scheme.

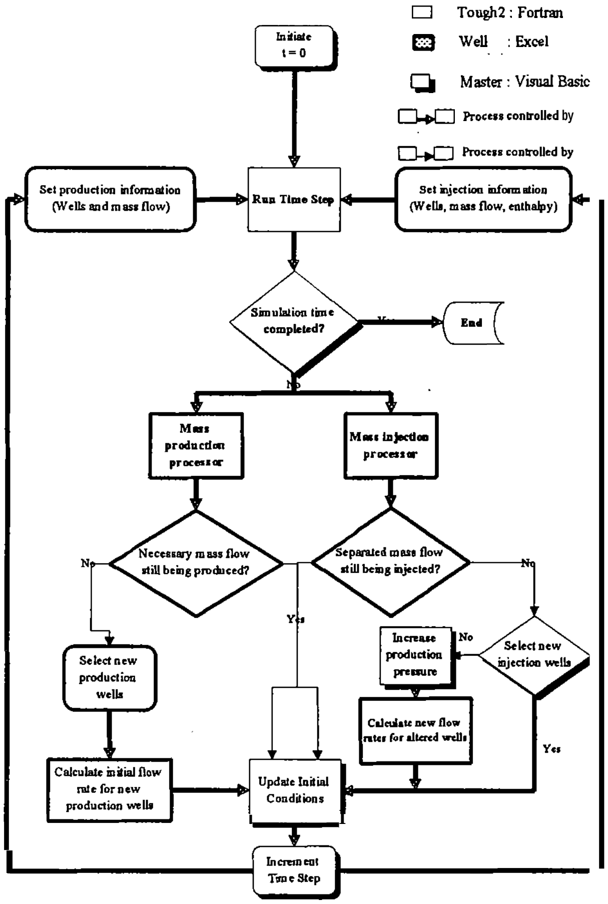


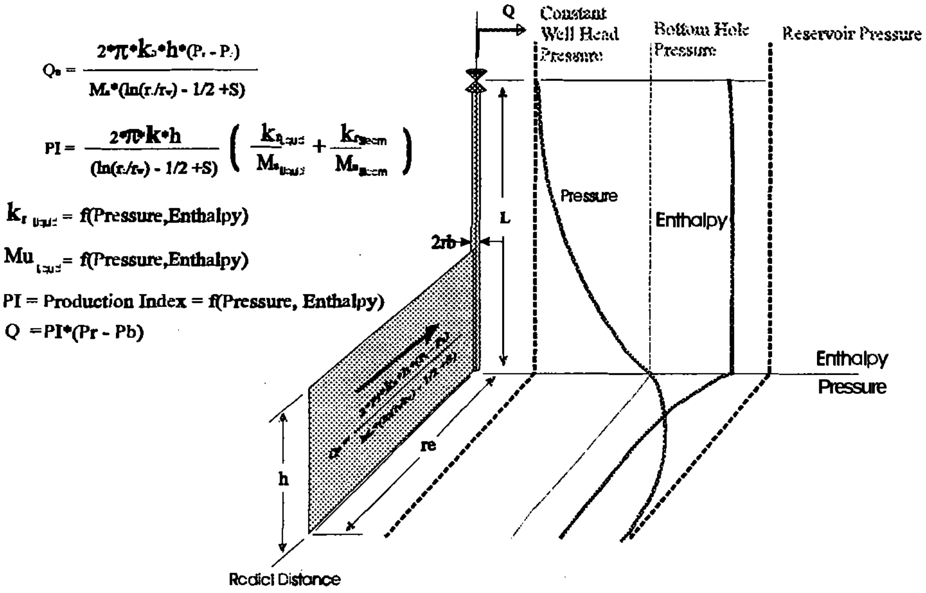
Fig. 2 Integral Forecasting Process

3.0 COUPLING THE RESERVOIR AND WELLBORE SIMULATORS

For calculating the mass flow delivered by a well operating at a given constant wellhead pressure, the well geometry, casing characteristics and Bottom Hole conditions (pressure and enthalpy) are required. For calculating the mass flow flowing from the reservoir towards the wellbore, the reservoir pressure and enthalpy, the reservoir hydraulic properties and the Bottom Hole pressure are required. To couple these two calculations an isoenthalpic process from reservoir to wellhead is considered. Then the problem becomes a one of determining the Bottom Hole pressure which renders the same mass flow rate when calculated from either the wellbore or the reservoir sides.

Considering the problem from the reservoir side, the mass flow towards the wellbore is calculated using a semi-permanent radial flow equation (Fig. 3). The procedure is simplified, by defining a Productivity Index (PI) which will be function of the reservoir's hydraulic properties and fluid defined properties (relative permeability and viscosity). These latter properties in turn, will be function of the fluid's pressure and enthalpy. The advantage of using the Productivity Index is that it takes a constant value when the thermodynamic conditions (pressure and enthalpy) of the fluid are known. Then, the mass flow equation takes the form of a linear equation with the Bottom Hole pressure as independent variable and the mass flow as dependent variable (refer to Fig. 3). *An* equation like this, is very easy to manipulate.

The reservoir simulator delivers values of pressure and enthalpy (among other values) for each of the elements in which the discrete model of the reservoir has been subdivided. The present method assumes that the reservoir pressure and enthalpy required in the radial flow calculations are those values calculated by the reservoir simulator for the specific production elements and that the required hydraulic properties are those of the specific production element. Once the production element is selected, these values are known and then, the PI value *can* be readily calculated.



$$Q_s = \frac{2 \cdot \pi \cdot k_s \cdot h \cdot (P_r - P_w)}{M_s \cdot (\ln(r_e/r_w) - 1/2 + S)}$$

$$PI = \frac{2 \cdot \pi \cdot k \cdot h}{(\ln(r_e/r_w) - 1/2 + S)} \left(\frac{k_{r_{liquid}}}{M_{u_{liquid}}} + \frac{k_{r_{steam}}}{M_{u_{steam}}} \right)$$

$k_{r\ liquid}$ = f(Pressure,Enthalpy)

Mu_{liquid} = f(Pressure,Enthalpy)

PI = Production Index = f(Pressure, Enthalpy)

$Q = PI \cdot (Pr - Pb)$

Fig. 3 Basic Concept of the Coupled Flow

Now, considering the mass flow problem from the wellbore side, using a wellbore simulator, Bottom Hole pressures for constant enthalpy values and different values of mass flow can be tabulated (Fig. 4). Curves (Mass Flow vs. Bottom Hole Pressure) can be plotted for different constant enthalpy values.

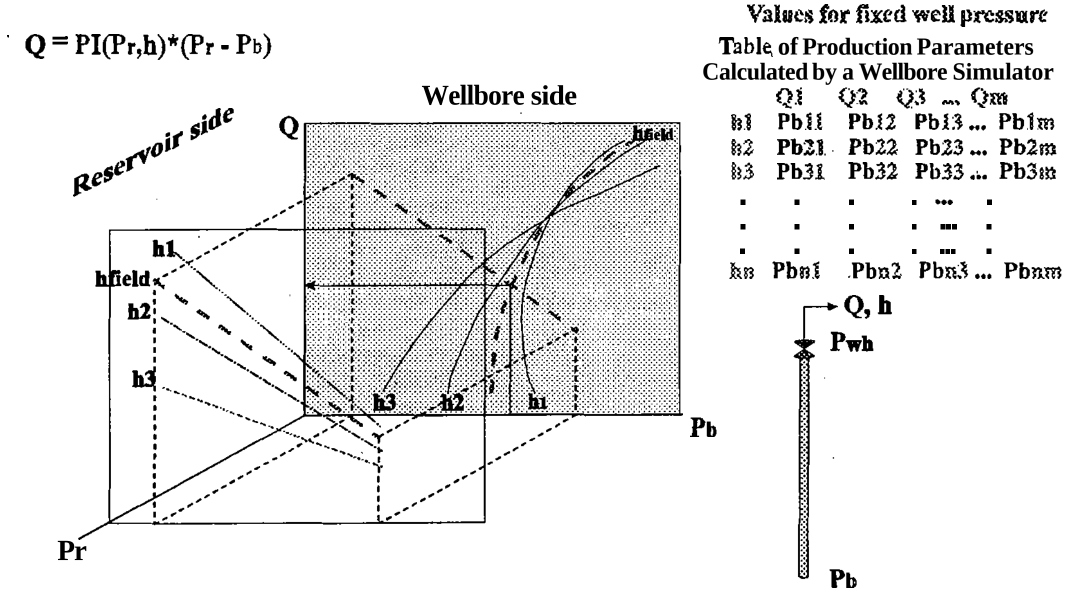


Table of Production Parameters Calculated by a Wellbore Simulator

	Q1	Q2	Q3	...	Qm
h1	Pb11	Pb12	Pb13	...	Pb1m
h2	Pb21	Pb22	Pb23	...	Pb2m
h3	Pb31	Pb32	Pb33	...	Pb3m
.	.	.	.	...	.
.	.	.	.	...	.
.	.	.	.	...	.
hn	Pbn1	Pbn2	Pbn3	...	Pbnm

Fig. 4 Procedure to find coupled reservoir/wellbore mass flow

When reservoir enthalpy is known for a specific production element in the model, the Bottom Holes pressures for the different tabulated mass flows can be calculated by interpolation. Then the curve (Mass Flow vs. Bottom Hole Pressure) for the enthalpy value rendered by the reservoir simulator can be plotted (refer to Fig. 4). Since the Mass Flow and Bottom Hole pressure have the same meaning for both, reservoir side and wellbore side, the same graph can be used to plot the straight line derived for different Bottom Hole pressures and by using the calculated PI value. The intersection of the curve and the straight line will render the Mass Flow and Bottom Hole pressure which are common to the wellbore side and to the reservoir side.

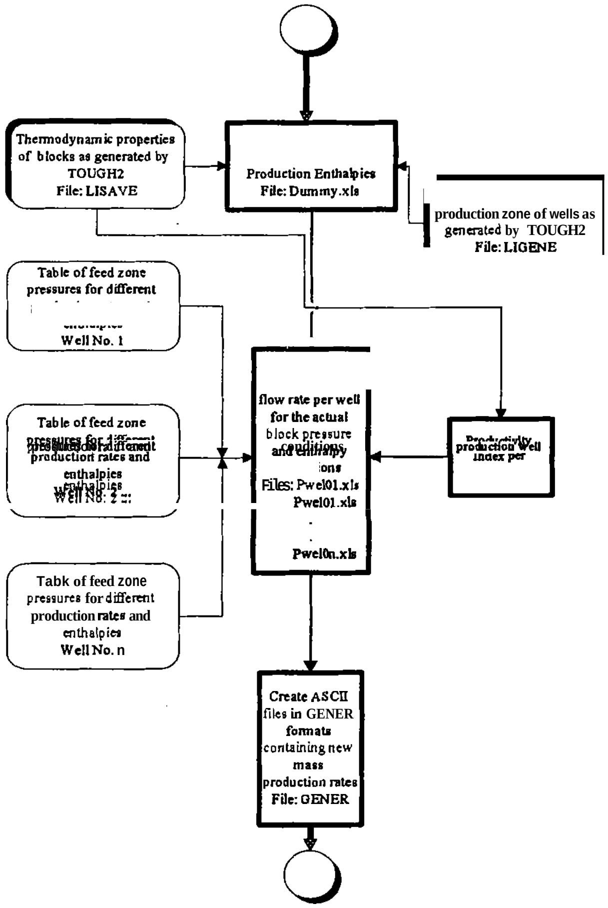


Fig. 5 Mass Production Processor

The above procedure, valid for a single feed point in the wellbore, is simple and can be easily extended to a multiple feed point problem. Care must be exercised when designing the discrete model of the reservoir so as to locate each known feed point in a different element of the model.

The procedure of linked mass flow rate calculation is easily implemented using EXCEL sheets and macros for wells (refer to Fig. 5). The only thing which is required is that for each time step, the pressure and enthalpy of production elements (as calculated by the reservoir simulator) are transferred to the well's EXCEL sheets. In the case of the tool we developed, the new mass extraction rates are automatically copied (through object linking) to another EXCEL sheet where the integration of all production information is done. This sheet, the Power EXCEL sheet, calculates power output and separated water quantities for the selected power scheme. Also, the Power EXCEL sheet prepares ASCII data of the generation rate to be supplied to the reservoir simulator for the next time step. The information is then updated, through object linking, to **GRASP** so that this central controller interactively and in "real time" can present the results of simulation to the user.

4.0 COUPLING THE RESERVOIR AND SILICA DEPOSITION SIMULATORS

The used silica deposition simulator **SDRF,** requires the input of the geometrical information of the reinjection wells, reinjected mass flow, reinjection temperature, chemistry of fluids, reservoir pressure and hydraulic properties of the reinjection formations. The simulators calculates the reduction of permeability of formations due to silica scaling and the corresponding variation of the water level elevation considering the damage to the well's injection capacity and the reservoir pressure. The information which SDRF requires from the reservoir simulator are the values pressure and enthalpy of the reinjection element. The simulator was copied, as a macro, into the EXCEL sheet controlling the mass production calculations, "the Power EXCEL sheet". In this sheet it receives the required information for the silica scale, reduction of the "kh" value and water level elevation calculations (refer to Fig. *6).* The Power EXCEL sheet is programmed to keep the control of the performance of reinjection wells, to prepare ASCII data of the injection rate to be supplied to the reservoir simulator for the subsequent time step calculation as well as to produce graphical outputs. At the end of every time step the Power EXCEL sheet updates GRASP for real time graphical presentations to the user.

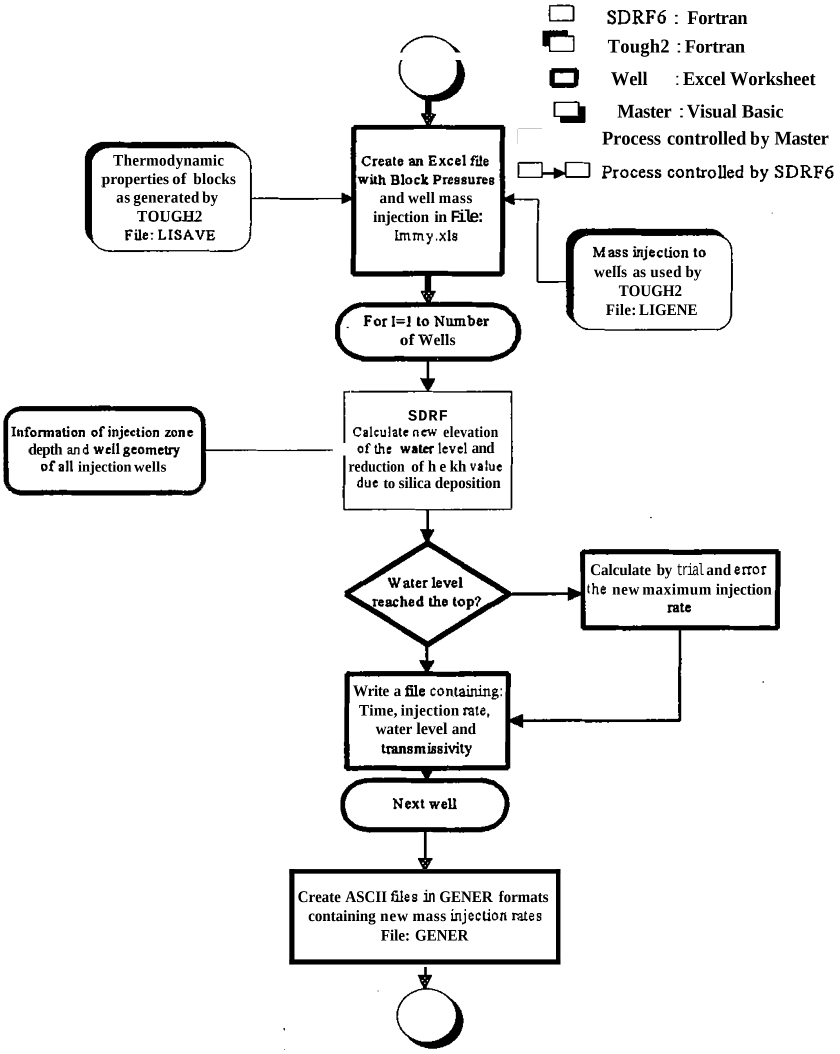


Fig. *6* Mass Injection Processor

5.0 RESULTS AND CONCLUSIONS

The procedure was implemented in a Pentium 133 MHz laptop computer. The testing was done using a calibrated model of number of 500 elements. All production and reinjection elements were defined as Double porosity model. The model contained 20 production wells (eleven starting wells and 9 targets for substitutions) and 10 reinjection wells *(5* starting wells and *5* targets defined for substitutions). The simulation time was 30 years and the calculations were carried out with time steps duration of one month. Fig. 7 and Fig. 8 depict the results of these calculations.

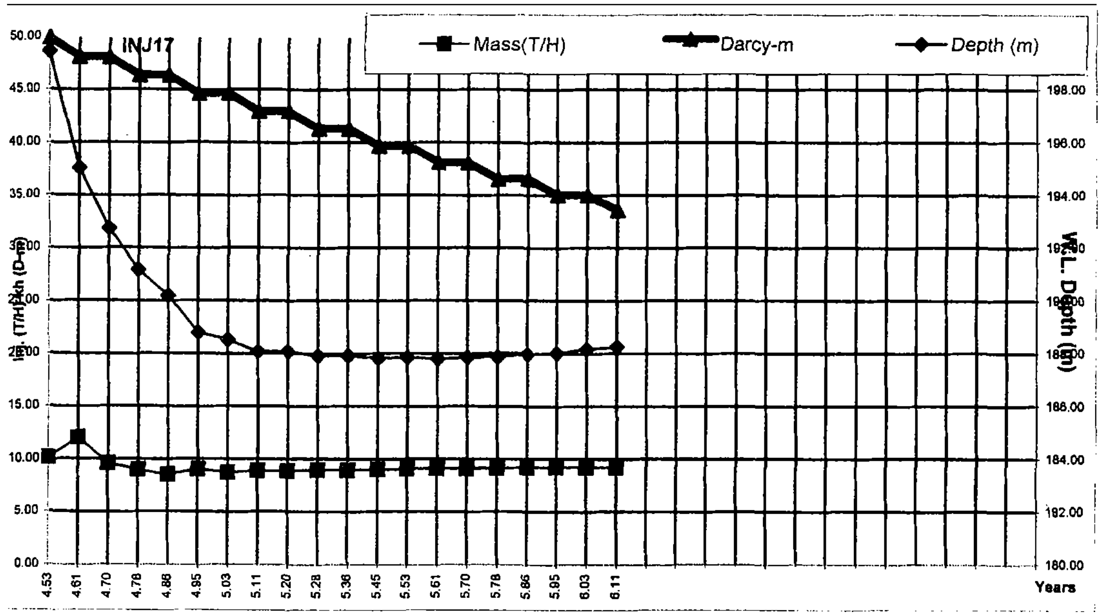


Fig. 7 Sample of Reinjection Characteristics as Calculated by GRASP

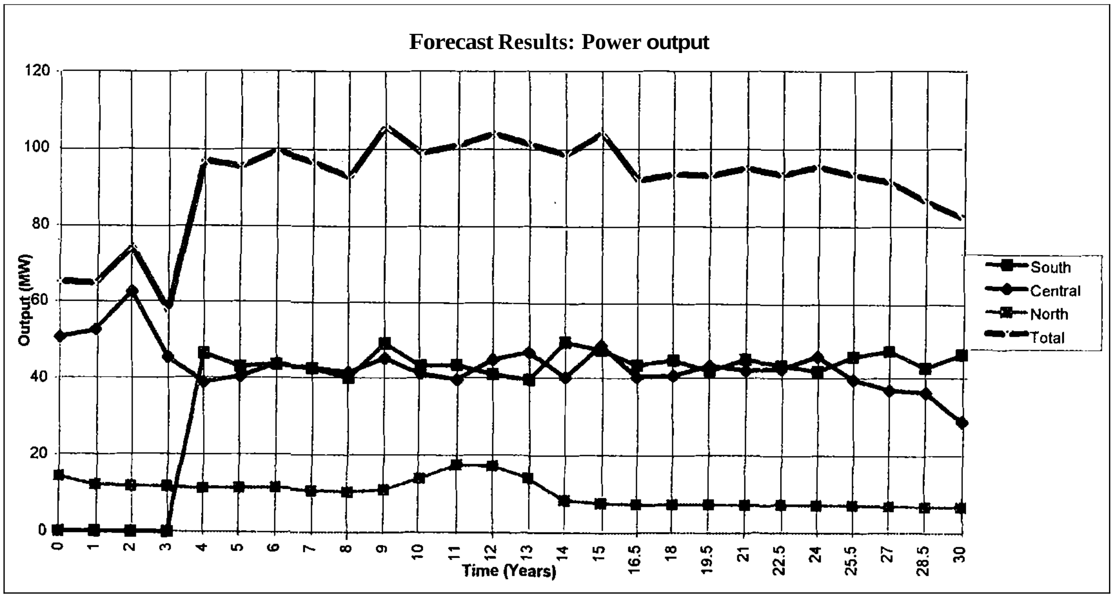


Fig. 8 Simulated **Power** Output as Caluculated by GRASP

Though the procedures is being improved, it offers a powerful tool for selecting the optimal exploitation scheme and power cycle. These two aspects are crucial for maintaining geothermal energy competitive within the other choices of energy generation and to permit the complete utilisation of the environmental friendliness which geothermal energy can provide to those countries blessed with this resource.

Acknowledgements

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