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GEOTOOL: A COMPUTER PACKAGE TO AID
GEOHERMAL RESERVOIR ASSESMENT

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ABSTRACT

This paper describes a software package, GEOTOOL, designed to help characterization and assesment of geothermal fields. GEOTOOL offers numerics and graphic technique integrated in a user-friendly and interactive system. The package performs a wide variety of tasks that are often tackled without the help of a computer. A great advantage of GEOTOOL is that it is linked to SIGEO, a comprehensive geothermal database package that stores most of the information pertaining to all the Mexican geothermal fields. Furthermore, the results obtained by means of GEOTOOL can be stored for later use in SIGEO. GEOTOOL is operating in a VAX/VMS computer system.

INTRODUCTION

Two years ago we developed a computerized system to manage information on exploration, development and exploitation of geothermal resources in México. The system, called SIGEO, is described in detail by Sarmina (1983), and Rodríguez and Sarmina (1985). It consists of three components: (a) the database, (b) a set of input programs, and (c) a set of output programs to produce reports. SIGEO has been built to allow the definition of new types of data and new reports associated with the new data. In its current version, up to 9000 variable types can be defined together with a great variety of reports.

Even though SIGEO is very flexible to admit new types of data and to produce many user-defined reports, it only supports reports in tabular format; moreover, it lacks the capacity to perform calculations with the data. To complement SIGEO's capabilities we have designed and implemented a package of computer programs, GEOTOOL, which includes analytical computations, graphics subroutines in 2 and 3 dimensions and the necessary software to allow the user to

operate the programs interactively, to aid in various tasks related to geothermal reservoir evaluation.

The current version of GEOTOOL includes:

Analytical tools to calculate stabilized temperatures, geothermometers, chemical indexes, enthalpy, water- and steam-flowrates, and water density.

Analytical and graphical tools to support pressure tests analysis of homogeneous and double-porosity geothermal reservoirs: Type-curve method, pressure test by Horner's and by the MDH method, and two-rate and variable-rate pressure tests.

Graphics tools to display: production output curves, time-evolution of different variables, profiles of different variables versus depth and 3-D distributions of different variables in the field.

GENERAL STRUCTURE OF THE PACKAGE

The general structure of GEOTOOL is depicted in fig. 1. GEOTOOL has two structural levels: the first level is constituted of 11 modules, which are the user view of the package. The second level includes various general-purpose subroutines which are used by the modules.

LEVEL 1: MODULES

- | | |
|--------------------|--------------------------|
| TYPE CURVES | STABILIZED TEMPERATURES |
| HORNER'S METHOD | GEOHERMOMETERS |
| MDH METHOD | PRODUCTION OUTPUT CURVES |
| TWO-RATE FLOW TEST | VERTICAL PROFILE PLOTS |
| MULTIPLE-RATE TEST | 3-D DISTRIBUTION |
| TIME EVOLUTION | |

LEVEL 2: SUBROUTINES

- | | |
|-----------------------|----------------------|
| X-Y PLOTS | ENTHALPY CALCULATION |
| 3-D GRAPHICS | WATER AND STEAM |
| PROFILES | FLOWRATES |
| STRAIGHT LINE FITTING | WATER DENSITY |
| β-SPLINES FITTING | |

Fig. 1.- General Structure of GEOTOOL.

Each module performs a particular task, as described in the next section. The modules are interactive and user-friendly (menu driven), such that, their execution does not require any special training. The data required by the modules are automatically taken from the SIGEO database. For that, the user has only to provide: the geothermal field identifier, the well key, the test or variable identifiers and the appropriate dates.

The general-purpose subroutines include graphics routines to plot Y vs X charts, profiles, contour lines, and 3-D surfaces. These subroutines were built by means of PAGRA, a basic graphics package developed in-house (León and Carmona, 1983). Additionally, GEOTOOL has various subroutines to perform analytical calculations (e.g., straight line fitting, curve fitting by β -splines, enthalpy calculations, etc.).

Fig. 2 shows the general interaction environment of a module of the package.

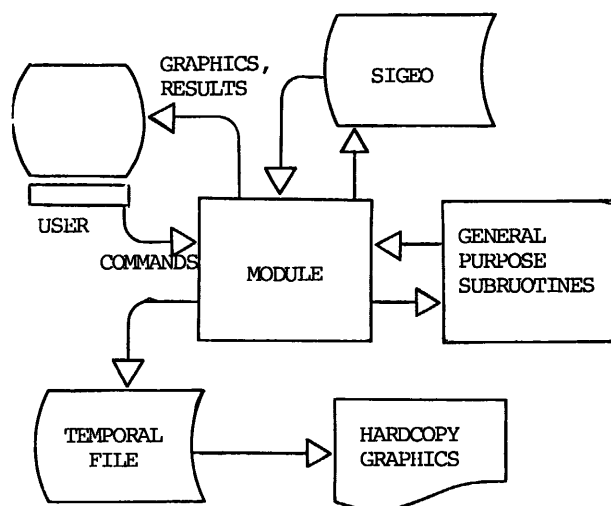


Fig. 2.- Interaction Environment of a Module

All modules include the following processes:

Input. The data are taken from SIGEO, where they have been validated; GEOTOOL assumes they are correct. The validation process consists of checking the values against validity ranges established by the user. The data from SIGEO is always in the International System of units.

Calculations. These are performed according to the selected module. In all cases, the user can store the results in the database if the results are going to be used later. Additionally, the modules validate the results by the process

mentioned above. In some cases the results are converted from the International System of units to the one used by CFE in the fields.

Graphics. With the data from the database and/or the results obtained, a module is able to output graphics. Under user commands the module displays the graphics on a CRT screen or creates a temporal file to send the graphics to an appropriate printer later. All graphics are drawn using several types of broken or continuous lines.

MODULE DESCRIPTION.

In the following paragraphs we describe the currently implemented 11 modules. First, we present five modules which are specific to aid pressure test analysis. Then, the rest, which perform a variety of tasks ranging from determination of stabilized temperatures to geochemical calculations.

Type curves. This module plots the data of injectivity or buildup tests in the standard log-log form. An example is shown in fig. 3. The plots are drawn on transparent paper in the standard scale used by most published type curves. These include Earlougher & Kersch (1974), Agarwal, Al-Hussainy & Ramey (1970), and Bourdet & Gringarten (1980). The necessary downhole flowing pressures and corresponding times are obtain from SIGEO.

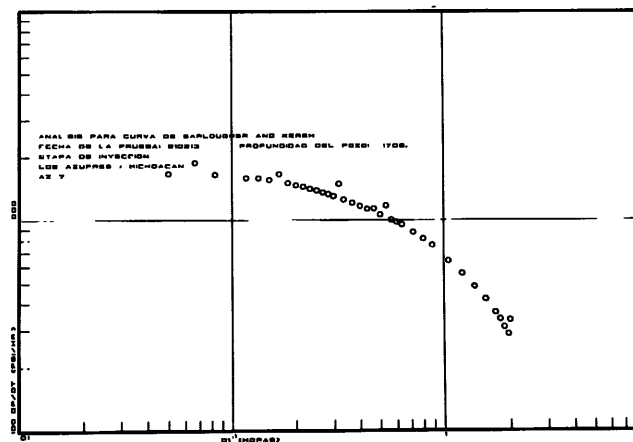


Fig. 3. Example of standard log-log plot, in this case, for the type-curve of Earlougher and Kersch.

Horner's method. This module is specific for the analysis of buildup and falloff tests by Horner's (1951) method. The required data, taken from SIGEO are: injected flowrate, injection time, flowing downhole pressure and elapsed time for each pressure reading. Under user commands the module graphically displays on the CRT screen a plot of

P_{wf} vs $\log((t_p + \Delta t)/\Delta t)$

(nomenclature at the end of the paper). The user provides the time interval unaffected by wellbore storage that he wishes to analyze (see fig. 4). To chose this interval, the user can resort to the log-log plotting capabilities of the module described in the preceding paragraph. Using the selected points the module adjusts a least square straight line to them, and displays the results on the screen (see fig. 5). Interactively, the user can terminate the session here or select another interval for analysis, and/or eliminate individual data points and repeat the process until he is satisfied. This module outputs the absolute value of the slope of the straight line m , the intercept b , and the transmissivity Kh/μ .

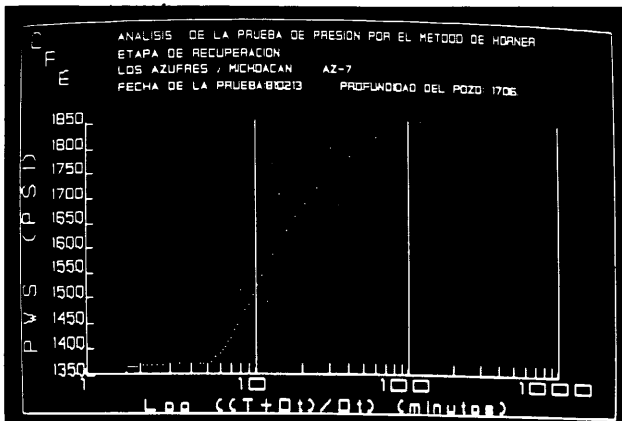


Fig. 4. CRT display of the data points for interval selection.

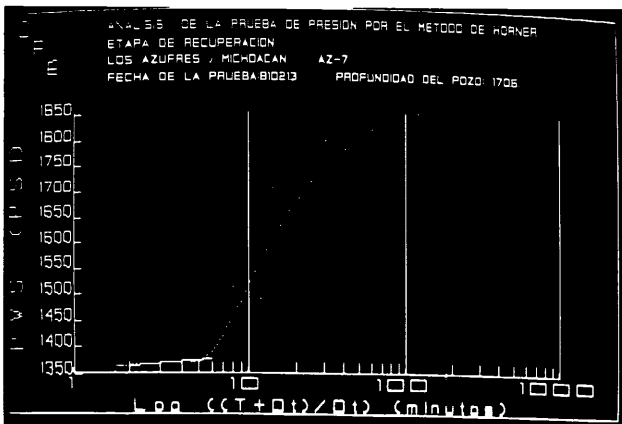


Fig. 5. Straight line fitted to the linear portion of the semilog plot.

MDH Method. This module helps analyze drawdown and buildup, and injectivity and falloff pressure tests by the MDH method (Miller, Dyes and Hutchinson, 1950). As in the module previously described, the

required data are taken from SIGEO. The user interaction with, and the results produced by this module are the same as for the Horner's module, except that the plot displayed is that of

P_{wf} vs $\log(\Delta t)$.

Two-rate Flow Test. This module is specific for the analysis of two-rate flow tests (Russell, 1963). The data taken from the database are: the well radius in the production zone, the flowrates (q_1 , q_2), the time interval t_1 during which the well produced at the rate q_1 and the downhole flowing pressure at the running testing time Δt . Optionally, the flowrates can be computed by means of the usual sharp-edged orifices (James, 1965), or by the lip pressure (James, 1970) methods. The module performs the necessary computations to display on the screen a plot of

$$P_{wf} \text{ vs } \log((t_1 + \Delta t)/\Delta t) + (q_2/q_1) \log(\Delta t) \quad (1)$$

The results are automatically checked to be within user-established ranges. At this stage, the user may select to either display or print plots of the flowrate vs. time, and of P_{wf} vs. time, or to proceed straight to the analysis. To carry on the analysis, a proper time interval must be selected as in previous modules. When the selected interval is input, the module: (a) fits a straight line to the data in the interval; (b) displays a plot of expression (1) on the screen; and (c) computes and displays the slope m , the intercept b , the transmissivity Kh/μ , the skin factor S , and the false pressure p^* which can be used to estimate the average reservoir pressure. The process can be repeated for another interval, at the user's will.

Multiple-rate test. This module helps analyze multiple-rate tests by Odeh's (1965) method. The data requirements and the capabilities of this module are similar to those of the preceding one,

except that a plot of $(P_i - P_{wf})/q_N$ vs

$$\sum [(q_j - q_{j-1}) \log(t - t_{j-1})] / q_N$$

with the sum taken from $j=1$ to N , is produced. As before, the options to compute the flowrates from field measurements, to display or print plots of the flowrate vs time, and of p_{wf} vs time, exists. Also as before, the interval in which a least squares straight line has to be fitted to the data, must be selected by the user. The results obtained in this module are: the slope m , the intercept b , the transmissivity Kh/μ , and the skin factor S .

Production output curves. This module computes the enthalpy and the water and steam flowrates from field measurements taken during production tests, and plots them. The necessary field data are: atmospheric pressure at the field, wellhead pressures, lip pressures, diameter of the discharge pipe, weirbox dimensions, water head in the weirbox, water density, gas/steam ratio, and diameter of the choking orifice. The enthalpy and the water and steam rates are computed by the lip pressure method (James, 1970), at atmospheric pressure, and at separation pressures of .8 and 1.0 MPa. These results are checked against user-established validity ranges. The module produces the following graphics: water and steam flowrate vs. wellhead pressure for the three separation pressures mentioned in the preceding paragraph, enthalpy vs. wellhead pressure, and choking orifice diameter vs. wellhead pressure (the last two for separation at atmospheric pressure).

Stabilized temperatures. This module computes the stabilized temperature of the formations penetrated by the well, from temperature data gathered during drilling. The method used for the computations is that of Horner (e.g., Chiang and Chang, 1979). The drilling fluid circulation time, depth, the times at which the temperatures are measured, and the corresponding downhole temperatures are input from the database. The resulting stabilized temperatures are stored in the database for future use, such as plotting vertical profiles or the 3-D distribution of these temperatures.

Geothermometers and chemical indexes. The geothermometers and chemical indexes are computed by this module on the basis of the chemical analysis of separated brines. The available geothermometers are: Na-K-Ca (Fournier and Truesdell, 1973), silica (Fournier and Rowe, 1966) and revised silica (Fournier and Potter, 1982). The computed chemical indexes are: Na/K,

K/Na and Ca/Na. The user can select the geothermometers and indexes he wishes to obtain. The results are generated in tabular form, and stored in temporal files which can be displayed on the screen or sent to a printer; they can also be permanently stored in SIGEO.

Time evolution of variables of interest. The behavior of a variable versus time can be plotted with this module (fig. 6). The available observation periods in the module are: one month, one year and several years. The currently available variables for plotting are: reinjection temperature, downhole temperature, downhole pressure, wellhead pressure,

water flowrate, steam flowrate, total (water and steam) flowrate, steam quality derived from the steam chemical analysis, enthalpy calculated from wellhead measurements, enthalpy based on the saturation temperature given by the geothermometers, chemical indexes and geothermometers. The last three are computed in this module, the rest are obtained from SIGEO.

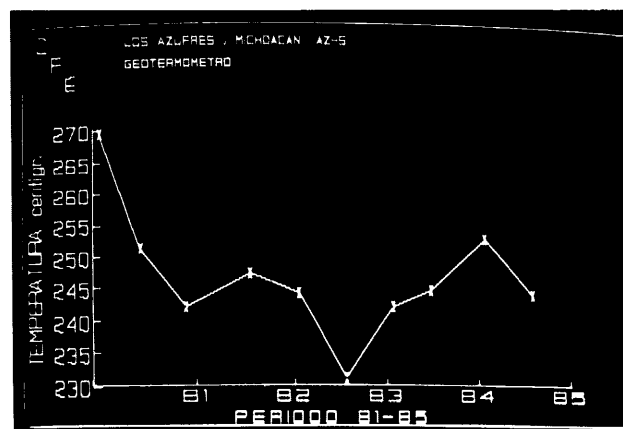


Fig. 6. Example of time evolution of a variable.

Vertical-profile plots. This module generates graphics to show the profile of a variable versus the depth of the well (fig. 7). The necessary data are taken from SIGEO. The currently available variables for plotting are: downhole pressure, downhole temperature, stabilized temperature, and percentages of hydrothermal alteration of several minerals in the lithologic column of the well.

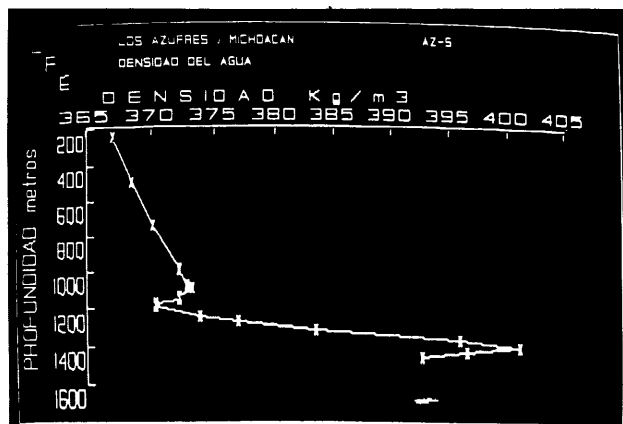


Fig. 7. Example of a profile.

3-D distribution of variables. The module produces 3-D representations of the spatial distributions of selected variables. There are two options: 2-D contour lines and 3-D surfaces. The data for both

options are the values of the variables at the coordinates of the wells, and in certain cases, at a given depth. The module uses β -splines (Hayes and Halliday, 1974) to interpolate values for coordinates uniformly distributed on the X-Y plane. The variables are the following: topography (related to sea level), stabilized temperature, reservoir pressure, enthalpy calculated from wellhead measurements, gas/steam ratio, mass production, steam quality, geothermometers and chemical indexes. In the case of contour lines it is possible to select up to 8 isovalues and up to 8 types of lines (continuous, discrete, mix, etc.). There are three types of contour precision, regular, fine and very fine, that allow the user to save computer time at the expense of contour precision, if desired. Fig. 8 shows an example of a contour line plot.

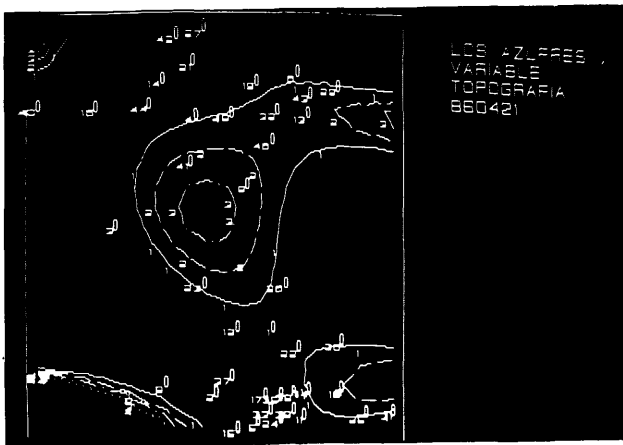


Fig. 8. Example of contour lines.

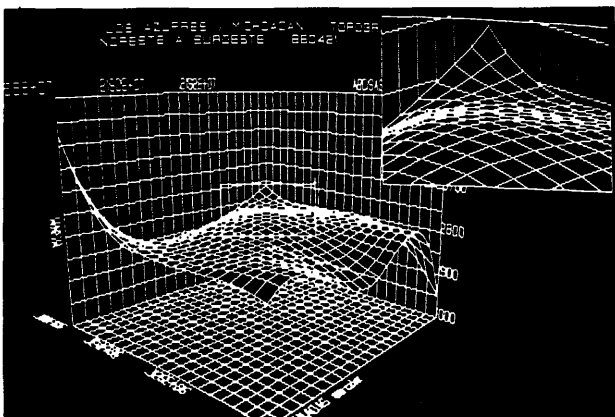


Fig. 9. Example of a 3-D Surface.

The module has the following options to present 3-dimensional surfaces: 8 different views (north-south, east-west, nw-se, ne-sw, and their reciprocals); three contour precisions; contour lines can be drawn on the surface and projected on the Y-X plane. The elevation from which the 3-D surfaces are viewed is set automatically by the module, to avoid possible problems of perspective. Additionally, the user can request a "ZOOM" to amplify selected areas from the display. Fig. 9 shows an example of a 3-D surface.

CONCLUSIONS.

We have developed a computer package designed to aid in the assesment of geothermal fields. The outstanding characteristics of the package are, its user-friendliness, and its ability to compute results from data stored in the SIGEO database, to store these results back in SIGEO, and to plot a great number of useful graphs. Furthermore, the architecture of GEOTOOL is flexible as to permit the definition of new modules to perform additional tasks not currently implemented. This package is an important complement to SIGEO that significantly enhances its usefulness.

NOMENCLATURE

- b: intercept on semilog plot
- Kh/μ : transmissivity
- m: slope of linear portion of semilog plot
- P_i : initial pressure
- P_{wf} : flowing downhole pressure
- p^* : false pressure
- q: flowrate
- S: skin factor
- t: elapsed time
- t_j : the time interval elapsed until jth. measurement was taken
- t_p : equivalent time well was on production or injection before shut-in
- t_1 : the time interval t_1 during which the well produced at the rate q_1
- Δt : running testing time

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REFERENCES

- Agarwal, R.G., Al-Hussainy, R. and Ramey, H.J., Jr., 1970 (sept.). An investigation of wellbore storage and skin effect in unsteady liquid flow: I. Analytical treatment. Soc. Pet. Eng. J., p. 279-290.
- Bourdet, D. and Gringarten, A.C., 1980. Determination of fissure volume and block size in fractured reservoirs by type-curve analysis. Soc. Pet. Eng. Paper 9293, 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers, Dallas, Texas.
- Chiang, C.Y. and Chang, C.R.Y., 1979. Application of the Horner method to the estimation of static reservoir temperature during drilling operations. Proc. 5th. Stanford Workshop Geothermal Reservoir Engineering, p. 337-342.
- Earlougher, R.C. and Kersch, K.M., 1974 (july). Analysis of short-time transient test data by type-curve matching. J. Pet. Tech., p. 793-800.
- Fournier, R.O. and Rowe, J.J., 1966. Estimation of underground temperatures from the silica content of water from hot springs and wet steam wells. Am. J. Sci., v. 264, p. 685-697.
- Fournier, R.O. and Truesdell A.H., 1973. An empirical Na-K-Ca geothermometer for natural waters. Geochim. Cosmochim. Acta, v. 37, p. 1225-1275.
- Fournier, R.O. and Potter, R.W., 1982 (nov.). A revised and expanded silica (quartz) geothermometer. Geothermal Resources Council Bulletin, p. 3-12.
- Hayes, J.G. and Halliday, J., 1974. The Least-squares fitting of cubic spline surfaces to general data set. Journal of Maths. Applics., no. 14, p. 89-103.
- Horner, D.R., 1951. Pressure build-up in wells. Proc. Third World Pet. Cong., E.J. Brill, Leiden, Section II, p. 503-523.
- James, R., 1965. Metering of steam-water two-phase flow by sharp-edged orifices. Proc. Inst. Mech. Eng. v. 180, p. 549-558.
- James, R., 1970. Factors controlling borehole performance. Geothermics, special issue: U.N. Symp. on the Development and Use of Geothermal Resources, v. 2, p. 1502-1515.
- León, G. and Carmona, P., 1983. PAGRA, A graphical package (in spanish). Conference Proceedings, 11 th. IEEE, International Conference on Research, Development and Applications in Electrical and Electronic Engineering, Session 31, No. 5, p. 1-4.
- Miller, C.C., Dyes, A.B. and Hutchinson, C.A., Jr., 1950. The estimation of permeability and reservoir pressure from bottom-hole pressure build-up characteristics. Trans., AIME, v. 189, p. 91-104.
- Odeh, A.S. and Jones, L.G., 1965 (aug.). Pressure drawdown analysis, variable-rate case. J. Pet. Tech., p. 960-964.
- Rodríguez, G. and Sarmina, I., 1985. Use of computerized systems for the decision making process in geothermal energy. Author's papers, EPRI/IEE Geothermal Conference and Workshop, Session 5.
- Russell, D.G., 1963 (dec.). Determination of formation characteristics from two-rate flow tests. J. Pet. Tech., p. 1347-1355.
- Sarmina, I., 1983. Geothermal Information System (in spanish). Boletín IIE (ISSN 0185-0059), v. 7, no. 4, p. 161-166.