GEOBASE: A SOFTWARE PACKAGE FOR STORAGE AND ANALYSIS OF GEOTHERMAL FIELD DATA

Victor M. Arellano, Eduardo R. Iglesias,
Juan Arellano, Maurilio Carvajal and Rodolfo J. Torres

Instituto de Investigaciones Eléctricas,
Departamento de Geotermia
Apartado Postal 475, Cuernavaca 62000, Mor., Mexico

Key words - Geothermal database, exploration/exploitation management software, reservoir engineering software

ABSTRACT- We developed GEOBASE, a prototype version of a user-friendly, integrated software package for storage, processing and analysis of geothermal data. Essentially, GEOBASE is a computerized database that incorporates specialized applications. Each application retrieves the necessary data, in its required format, from a databank pertaining to a particular geothermal field. The main components of GEOBASE are: a control module, a database module, a data retrieval module, a generator of standard reports, a wellbore-flow numerical simulator, an expert system for performance analysis of production wells, an expert system for analysis of pressure well tests and a graphics module. This prototype runs in PC platforms 80286 and above, under the MS-DOS operative system. GEOBASE was successfully applied for extensive studies of the evolution of the Cerro Prieto geothermal field, for diagnostics of production wells and for analysis of pressure well tests. Its use significantly enhanced our group's productivity.

1. INTRODUCTION

Geothermal fields under exploration or exploitation generate prodigious amounts of complex, multidisciplinary data. Properly collecting, storing, updating and analyzing these data is central for the successful management of exploration or exploitation of geothermal fields. A popular way to implement these functions is to rely on computerized databases for storing, updating and retrieving the data. When necessary, the database is interrogated to provide appropriate datasets for specialized analysis.

Currently, these analysis are often performed by, or with the aid of, other software packages. For example, data are typically plotted as a first stage for analysis; production histories of troubled wells are processed for clues to diagnostic their problems; data from pressure well tests are analyzed by different techniques; the chemical composition of produced fluids is used as input to compute geothermometers; etc.

For years, our group followed this approach. Our experience demonstrated, however, that generating report files from the computerized database and transferring them to other directories or computers for processing/analysis by means of other programs, was time-consuming and inefficient.

Thus, aiming at enhancing our productivity, we developed GEOBASE, a prototype, integrated software package for storage, processing and analysis of geothermal data. Essentially, GEOBASE is a computerized information system that incorporates specialized applications. In this work we describe its architecture and uses and discuss its advantages and shortcomings.

2. ARCHITECTURE OF GEOBASE

The main components of GEOBASE (Fig. 1) are: a Control module, a Database module, a Data Retrieval module, a Standard Reports module, a Wellbore-Flow Simulator module, a Well Performance Analysis module, a Pressure Test Analysis module and a Graphics module.

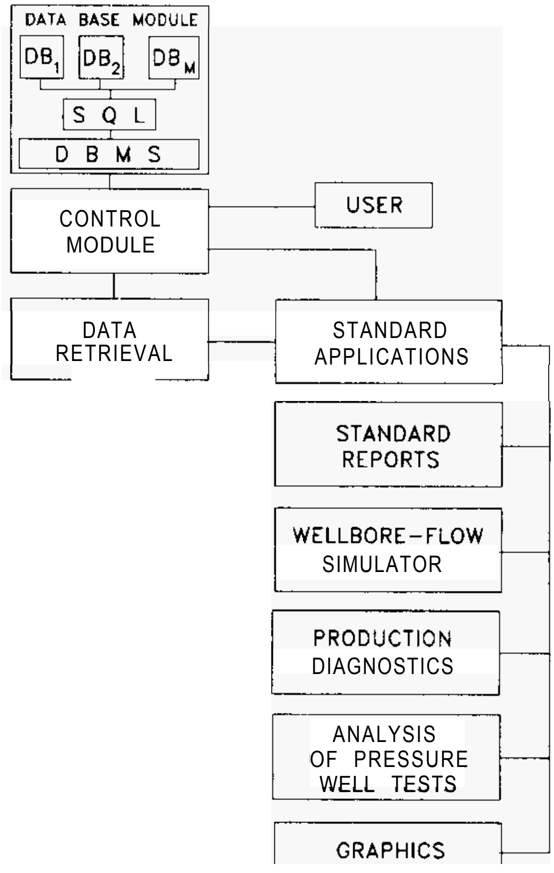

Fig. 1 Schematic of GEOBASE

2.1 Control module

The control module is a batch file, written in the MS-DOS command language. One of its main functions is to integrate the components of GEOBASE. To fulfill this function, it includes several other batch files and subprograms written in the C and SQL programming languages.

Another main function of this module is to provide a friendly, menu-driven user interface. In this spirit, the user interface is presented in Spanish, because it is targeted to Spanish-speaking users. The following sections illustrate several examples of the user interface, translated into English for this paper.

The main menu prompts the user to select one of the six currently available applications (Fig, 2).

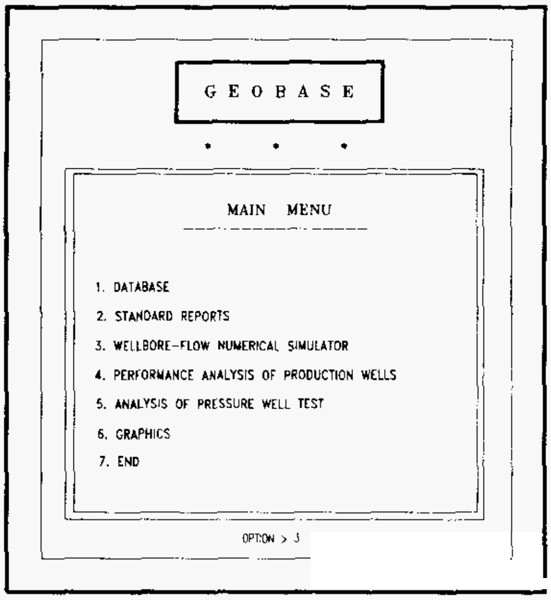

Fig. 2. Main menu

The Database module implements the main application. Distinct databases pertaining to particular geothermal fields may be stored in it (Fig. 1). Databases are identified by the name of their particular geothermal field. When GEOBASE is invoked, control is transferred to the Control module, which asks the user what particular geothermal field is to be loaded.

The Database module may be accessed directly from the Control module (Fig. 2) or via the other applications, through the Data Retrieval module. If accessed directly, the user works in the native environment provided by the database management system (DBMS) associated with the Database module (see below). Thus, he (she) can perform all the transactions and operations allowed by the DBMS, through the native resources, which include user-friendly screens. When the user exits the Database module, control is returned to the Control module, which asks whether another geothermal field (database) should be loaded. If the answer is negative, the original database remains active. Then the Control module displays the main menu.

When selected, the standard applications (Fig. 1) present *ad-hoc* menus. These prompt the user to identify which particular data is to be processed (e.g., date, well, log, etc.; see following sections). With this information the Control module automatically retrieves from the active database the dataset required for that particular problem and application. Then, it generates the necessary files, in the appropriate input format, and runs the application. When the user exits the application, control is returned to the Control module. As in the case of the Database module, the user is then asked whether to load another geothermal field, and a negative answer leaves the original database active. The Control module then displays the main menu.

2.2 Database module

We implemented the Database module on the basis of a PC, standalone version of INGRES. This is a sophisticated, relational DBMS, familiar to our group. The relational approach enables fast transactions and efficient storage, update and retrieval of the large multidisciplinary datasets necessary for geothermal reservoir exploration, assessment and management. Previously we had developed and used BDGEO, a departmental-level geothermal information system built on a multiuser version of INGRES (Iglesias *et al.*, 1994).

The main components of the Database module are the DBMS and the databases of the different geothermal fields (Fig. 1). These components are linked through the SQL-ANSI language, the *lingua franca* of databases. The DBMS performs many functions, including generation of user-friendly menus, creating and deleting databases, updating and consulting tables, creating and running reports or applications, providing help screens, storing database definitions, etc.

For GEOBASE we ported the well honed conceptual model and database definitions (e.g., fields, keys, tables, views, forms, reports, etc.) from BDGEO. The corresponding tables, fields and keys had been carefully developed and tested to facilitate its use from the exploration stage through the end of the commercial life of the field. Porting was greatly facilitated by using two versions of the same DBMS, and by several useful features provided by INGRES, including the SQL-ANSI programming language.

Currently the definition of each database includes 36 tables and the corresponding user-friendly forms to capture, consult and update data. There are also 79 standard reports that provide data specifically formatted for the remaining applications (see preceding and following sections).

When the Database module is accessed directly from the Control module (Fig. 1), the user-friendly interface provided by INGRES PC is displayed. The user may perform all the operations and transactions allowed by the DBMS. These include customized queries and reports interactively generated by means of the on-line SQL-ANSI language provided by the DBMS. Of course, the standard reports (see below) are also available in this mode.

Direct access to the Database module is a key feature of GEOBASE. It enables new and experienced users alike to get acquainted with the available information (e.g., which geothermal fields are stored?; names of the wells in field A?; how many temperature logs for well X?; dates of these logs?). Furthermore, unless one is extremely familiar with the information available for a particular geothermal field, it is generally useful to review the relevant information before running the standard applications.

2.3 Data Retrieval module

This module is accessed each time a standard application is selected from the main menu (Fig. 1). Three main functions are performed by it. First, it retrieves the particular datasets required by the standard applications from the active database. Then, it formats the retrieved datasets as required by the corresponding application. Finally, it writes the required formatted files to disk, in the appropriate directory. The exception to the final step is the standard reports module, see following section.

2.4 Standard Reports module

We wrote this module in C and embedded SQL programming languages. The Data Retrieval module mediates its access (Fig. 1). Its main function is to facilitate consultation of the standard reports required by the wellbore flow simulator, the expert system for performance analysis of production wells, the expert system for analysis of pressure well tests and the graphics module.

These applications process data associated with individual wells, that were collected at particular dates or during specific periods of time. For example, wellhead pressure, flowrate and fluid enthalpy are recorded during the periods in which the well is in production; data from a particular pressure test are typically collected in one day; etc. Thus, well names and dates constitute the main identifiers of standard reports. Currently, GEOBASE includes 79 standard reports. Help screens provide their names.

Users may choose from two types of reports (Fig. 3): screen reports and file reports (to disk). When choosing the first option, users are prompted to enter the name of a well. (Incorrect names, including the correct names of wells pertaining to an inactive database, generate error messages.) Then, users are asked to enter a date or a range of dates, depending on the standard report being consulted. (This screen also reminds the user of the date's correct format.) Reports are displayed either by screenfulls or continuous scrolling. Users may stop report display at will.

When the file report option is chosen, the user is required to enter a destination directory path and file name, for the output (report) file. Otherwise, dialogue screens are those just described for the first option.

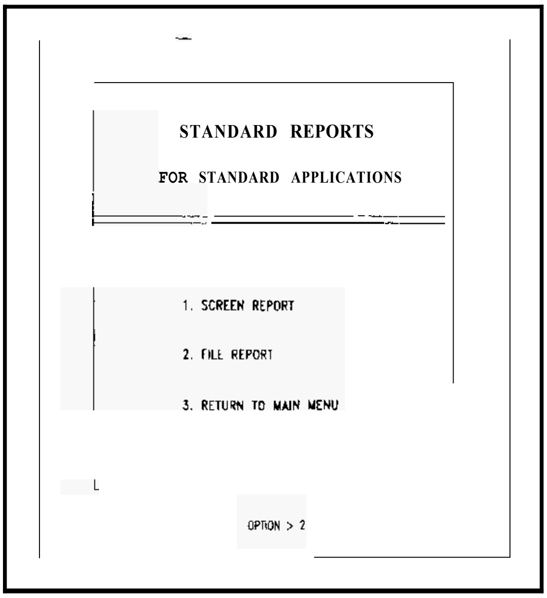

Fig. 3 Main menu of the Standard Reports module

2.5 Wellbore Flow Simulator module

The main function of this module is to run numerical simulations of associated mass and energy steady-state flows in geothermal wellbores. Results of these simulations provide estimates of a number of flow parameters (e.g., pressure, temperature, enthalpy, phase velocity, type of flow, etc.) as functions of depth. for given wellhead conditions.

We developed this module around a program named FLUPO (an acronym in Spanish meaning well flows). This is a geothermal wellbore flow numerical simulator, derived by our group from WELLFLO (Goyal et *al.*, 1980). We have used and periodically improved it for quite a few years. It is a one-dimensional, steady-state, finite-difference, multi-phase flow simulator for variable-diameter, vertical wells, written in FORTRAN.

The first screen of this module (Fig. 4) presents users with two options. After choosing the first one, users are asked to type a name for the file that will be created for input of the simulator. Then users must input the name of the well; the rules for valid names and relevant examples are displayed in this screen. The next screen asks the date at which to find the required production data. In the following screen one must type a filename for saving the results of the simulation run. At this point the module (a) retrieves from the active database the geometry of the tubular goods of the designated well and the wellhead pressure, enthalpy and flowrate recorded at the chosen date; (b) correctly formats that information and saves it in the designated input file; and (c) runs the simulation. Then it saves the corresponding results in the designated output file and displays them on-screen. At the end of this screen report one is presented again with the menu of Fig. 3.

When choosing the second option, to run a simulation using existing input files, users are only asked the filenames of the input and output files (all drives and directories are acceptable). Of course, only input files with the format required by the simulator are legal. Output files have standard format.

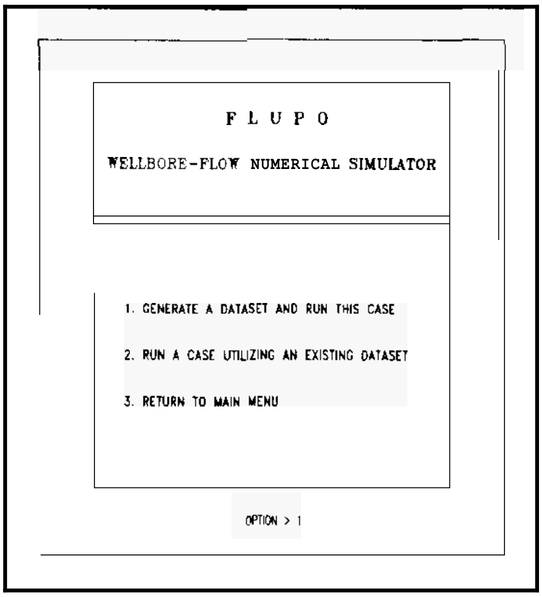

Fig. 4 Main menu of the Wellbore Flow Simulator module.

2.6 Well Performance Analysis module

We built this module on the basis of WELL-DR, an expert system for production diagnostics of geothermal wells (Arellano et *al.*, 1992) previously developed by our group. Its main purposes are to ascertain whether the production of a particular geothermal well is normal or impaired by pathological causes, and to diagnostic the causes. At the end of each analysis run, the diagnostics are listed, in order of decreasing probability. At any stage of the process, users may demand why a particular conclusion was reached, and get the corresponding explanation.

The main components of the Well Performance Analysis module are a shell (EXSYS, a commercial software package for development of expert systems), a Pattern Recognition module and its own WDgraphics module (inherited from WELL-DR). These are linked to the Database module of GEOBASE through the Control module and the Data Retrieval module.

The link to the Database module is necessary to retrieve production histories, production tests and information about the initial characteristics of the well, which are used to perform the analysis.

The shell includes three main components: a knowledge base, an inference engine and a user interface. The knowledge base uses a knowledge representation scheme based on production rules. These rules are of the well-known IF-THE-ELSE form. They include heuristic probabilities assigned by the developers to the conclusions of each rule. There are two types of conclusions: intermediate and final (or diagnostics). Intermediate conclusions are steps to reach diagnostics. WELL_DR's current implementation includes over one hundred rules and 24 diagnostics.

The inference engine drives the diagnostics process. It may operate either in forward or backward chaining mode. Normally, the inference engine tests rules by looking for the first rule with the first diagnostic in its THEN or ELSE part, and tests the IF condition of that rule. If any information of the IF conditions *can* be derived from other rules, those rules are invoked through backward chaining. The program then looks for the next rule relevant to the first diagnostic, etc., until it has gone through all of the rules. The process is then repeated for those rules relevant to the second diagnostic, third diagnostic. etc., until the list of the diagnostics is completely tested. If a rule is not relevant to any diagnostic, or does not assign values to a variable whose value is displayed at the end of a run, it will not be used.

The user interface implements dialogue boxes, in which WELL_DR asks for the necessary information (e.g., Fig. 5). Some dialogue boxes include technical graphs showing data trends used by the rules to reach conclusions. These graphs are generated by the WDgraphics module with input from the Pattern Recognition module (see below). Users may demand, at any stage of the process, why a particular conclusion was reached, and get the corresponding explanation.

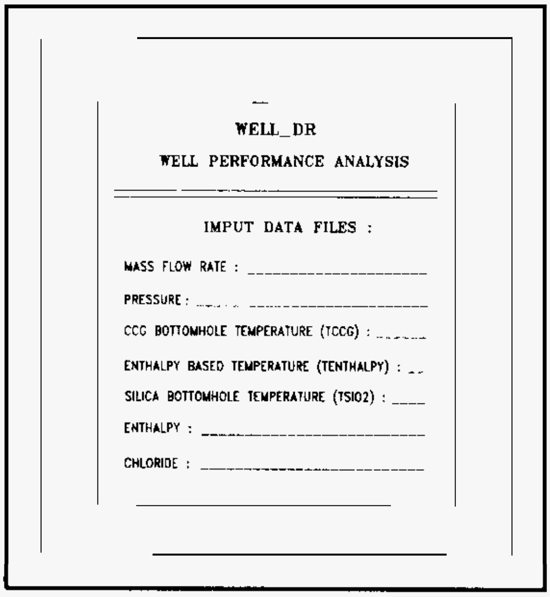

Fig. 5 Example of dialogue box of the Well Performance Analysis module.

We developed the Pattern Recognition module tailored to this application. To reach intermediate conclusions and diagnostics it is often necessary to decide whether certain data patterns fulfill certain conditions. For example, does the chloride concentration in the discharge of well Y generally increase, decrease or remain constant with time?; or, which temperature is generally greater over a given time period, that indicated by the silica, CCG or enthalpy geothermometer? The Pattern Recognition module implements appropriate techniques to answer this type of questions.

The WDgraphics module is also specially tailored to WELL_DR. It includes only the set of graphs used by WELL_DR, which include production histories, output curves, etc. We are using it in this prototype for expedience. It facilitates graphic display of data patterns and results of the Pattern Recognition module to users.

2.7 Pressure Tests Analysis module

We built this module around ANAPPRES, an expert system for automatic analysis of pressure well tests (Arellano *et al.*, 1990a; 1990b), previously developed by our group. ANAPPRES is a Spanish acronym meaning "well test analysis". This expert system can analyze single- and multiple-well pressure tests (e.g. Fig. 6) with constant or variable flowrates. Multiple-well tests may include arbitrary numbers of active and observation wells. In a single run ANAPPRES can infer 4 to 5 parameters (transmissivity, storativity, type of boundary, distance and angle to boundary). The reliability of the inferred parameters is quantitatively measured by standard statistical techniques. ANAPPRES is user friendly and faster than a human expert, requires limited experience on the part of the analyst, eliminates subjectivity and can handle complex cases and large datasets. It can also explain how and why it arrived at its conclusions. This last feature has didactic advantages for non-expert users, provides verification capabilities for expert analysts and increases confidence in the expert system.

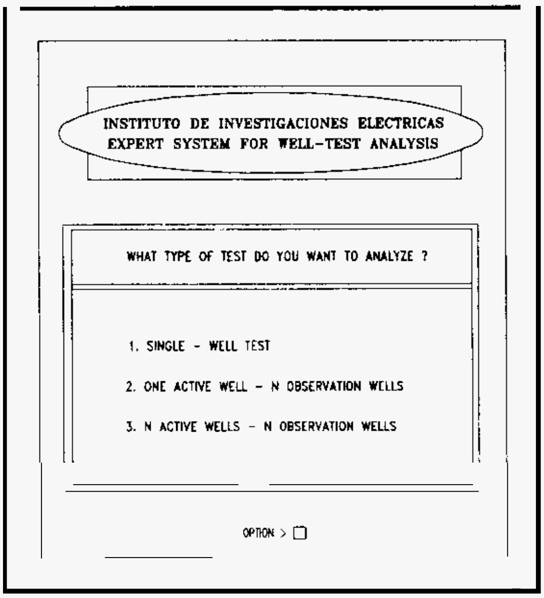

Fig. 6 Menu screen from the Pressure Test Analysis Module.

The main components of the Pressure Test Analysis module are a User Interface, an Inference Engine, a Knowledge Base, a Computational module and an Explanation module. Most of these modules are those of ANAPPRES.

The User Interface performs 5 main functions. It generates menus, inputs data, displays diagnostics and numerical results, generates graphics and displays explanations. All the corresponding subprograms, except those implementing the data input function, are originally from ANAPPRES. Data input is handled via GEOBASE's Data Retrieval module (see section 2.3).

The Computational module estimates reservoir parameters by minimizing the differences between observed- and modeled-pressure histories. Minimization is achieved by means of a non-linear least squares routine. A Chi-squared statistic, normalized to the observed pressures, provides a quantitative measure of the quality of the fit.

The Knowledge Base represents knowledge by IF-THEN-ELSE type production rules. It contains the knowledge necessary to perform the analysis. This includes quantitative criteria concerning the interpretation of the data (e.g., to decide whether the existence of a boundary is reliably indicated), the quality of the fits, etc.

The Inference Engine drives the analysis of the test, on the basis of the options selected, the input data, intermediate results provided by the Computational module and the information in the Knowledge Base. It operates in forward chaining mode. Every time the Inference Engine reaches a conclusion, it commands the User Interface to display it in the screen. Users are then asked if they request an explanation.

The Explanation module contains pre-formatted explanations for all the diagnostics and conclusions available to ANAPPRES. The se explanations are supplemented with information provided by the Inference Engine each time it reaches a conclusion or diagnostic. If the user chooses to request an explanation, the Explanation module passes the corresponding explanation to the User Interface, which displays it through its Display Explanation function.

2.8 Graphics module

We developed the Graphics module around GRAPHER. This is a commercial package, popular for engineering and scientific applications, that produces (X,Y) graphs.

Two main options are offered by this module. The first one automatically retrieves data from the database and produces standard (pre-defined) graphs. Data retrieval is mediated by the Data Retrieval module. Currently, most standard graphs are tailored to the existing standard applications. For example, there are standard graphs for results generated by the Wellbore Simulator Module, for production stories of single wells used as input by the Production Diagnostics Module, etc. For each standard graph, there is a pre-defined standard report

When this option is chosen, users are first asked to type a filename for a file in which to store the data retrieved from the database. Then they are presented with the names of the available standard reports for standard graphs and asked to choose one of them. Next, the name of the well and other relevant data (such as date or range of dates) must be entered. The selected dataset, correctly formatted for the graphics package is then retrieved and loaded, and the standard graph is generated. GRAPHER's main menu appears next, for fine-tuning of the graph and visual checks. At this point, the final graph may be plotted, printed or saved. Figure 7 was produced in this way. Finally, one may start another standard graph or return to GEOBASE's main menu.

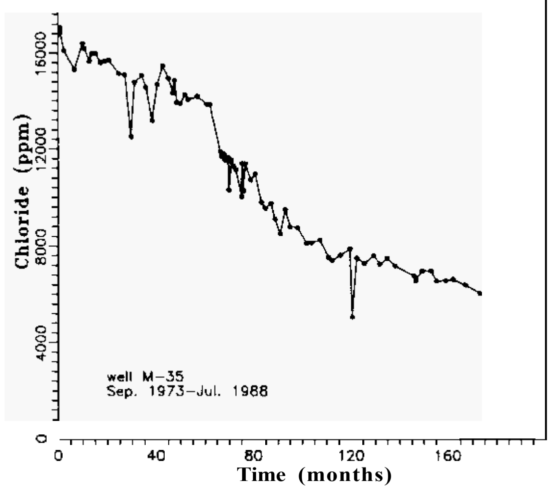

Fig. 7 Example of graph generated by the Graphics module

The second option is simply to use the commercial graphics package directly, as if from outside GEOBASE. When choosing this option, users are presented with GRAPHER's main menu. Then they can retrieve existing data files, graphs, axis, labels, annotations, colors, etc., from any drive and directory, or create new ones. They may also fit curves, review their graphs on-screen and print or plot them in the available peripherals. Exiting the commercial package leaves the user in GOBASE's main menu. We provided this option for convenience

One useful feature of GEOBASE is that new standard graphs (and the corresponding standard reports) may be added at any time. Thus, there is flexibility to accommodate new graphs stemming from the current applications and those associated with new applications eventually added to GEOBASE.

2.9 Hardware

GEOBASE's hardware requirements are modest by today's standards. It runs in PC platforms i80286 and above (or compatible), with a math coprocessor, a hard disk drive and at least 1 MB of RAM, under the MS-DOS operative system. Our current implementation includes an HP LaserJet III printer and an HP-7585B color pen plotter.

3. DISCUSSION AND CONCLUSIONS

This prototype demonstrated some of the advantages of an integrated package for storage and analysis of geothermal data. In particular, its use enhanced our productivity. This resulted mainly from the implementation of automatic data retrieval for the standard applications. Furthermore, we were able to successfully integrate ready-to-use commercial packages, which shortened development time and added robustness and flexibility to GEOBASE.

Some potential advantages of the integrated approach have not been realized yet. One of the most glaring is that the package should include only one graphics module, shared by all applications; this will be corrected in the next version of GEOBASE. Another is the present inhomogeneity of the user interface: the native screens of INGRES and GRAPHER, widely different and presented in English, mingle with the not-very-homogeneous user interfaces of ANNAPRES and WELL–DR, written in Spanish. Unifying the user interfaces in Spanish is a relatively simple issue. The real challenge is to homogenize the user interfaces of the commercial applications included in GEOBASE.

Finally, the current single-user version is the first stage of a more ambitious, multiuser project.

4. REFERENCES

Arellano, V.M., Iglesias, E.R., San Román G. and Nieva, D. (1992) WELL–DR An expert system for production diagnostics of geothermal wells, ***Proc. 2nd International Forum on Expert Systems and Computer Simulation in Energy Engineering,*** Univ. Erlangen-Numberg, Erlangen, Germany, pp. **21-2-1** to **21-2-6**

Arellano, V.M., Iglesias E.R., Arellano, J. (1990) ANAPPRES v2.0: A computerized expert system for well test analysis, ***Computers and Geosciences,*** Vol. 18(8), pp. 1105-115

Arellano, V.M., Iglesias E.R., Arellano, J., Pérez M. (1990) ANAPPRES v3.0 Automatic interference test analysis in personal computers, ***Transactions Geothermal Resources Council,*** **Vol. 14,** pp. 1271-1278

Goyal, K.P., Miller, C., Lippmann M.J., (1980) Effect of measured wellhead parameters and well scaling on the computed downhole conditions in Cerro Prieto wells, ***Proc. 6th Stanford Workshop on Geothermal Reservoir Engineering,*** Stanford Univ. SGP-'IT-50, Vol. **6**, pp. 130-138.

Iglesias, E.R., Arellano V.M., Torres R.J. and Carvajal M. **(1994).** BDGEO v3.1: a computerized database for geothermal reservoir assessment and management, ***15th PNOC-EDC Geothermal Conference,*** **24-25** Feb. **1994,** Hotel **Nikko** Manila Garden, Makati. Philippines.