ANAPPRES: AN EXPERT SYSTEM FOR INTERFERENCE WELL-TEST ANALYSIS

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ABSTRACT

We present ANAPPRES V1.0, the first version of a computerized expert system capable of analyzing constant- and variable-flowrate interference tests, in which there is one active well and an arbitrary number of observation wells, in liquid-saturated homogeneous reservoirs. ANAPPRES succesfully couples mathematical models, optimization techniques, heuristic knowledge and computerized graphics, a combination not often found in published expert systems. Its main advantages are that it is user friendly, requires essentially no experience on the part of the analist, eliminates subjectivity associated with earlier techniques of analysis, can handle complex cases and large data sets, completes the analysis of even the most complex cases (including plotting the results) in one run, and is significantly faster than a human expert.

INTRODUCTION

Interference tests, in which one or more active wells, and one or more observation wells participate, have distinct advantages over conventional well test in which only one well is involved. They ussually produce transmissivity and storativity values averaged over greater areas, can detect anisotropies in those properties, and can provide information about the existence and type (e.g., no-flow, constant-pressure) of hidrologic boundaries, and on their location.

For interference test analysis, a type-curve graphical technique (e.g., Earlougher, 1977) has been the standard of the trade for many years. In practice, this technique has the disadvantages of being restricted to relatively simple cases and of requiring subjective judgement for curve fitting. The popularization of digital computers brought about computerized analysis techniques (e.g., Earlougher and Kersch, 1972; Mc Edwards and Benson, 1981). These techniques, by use of regression and least-squares linear programming, eliminated the subjectivity previously associated with fitting a model to the observations, and provided the possibilities to study complicated systems and handle large quantities of data. However, the application of these techniques still requieres extensive experience on the part of the analyst, and, except in the simpler cases, is laborious. The laboriosity is associated with the necessity of running many times the same program, in cleverly selected sequences, with different subsets of data. The experience is required mainly for provinding initial guesses of the parameter solutions to start the programs, for applying adequate quantitative criteria for accepting a computed fit to the data (i.e., a solution), and for selecting the proper sequence to run the program and the corresponding data subsets.

This work describes ANAPPRES V1.0 (ANAlizador de Pruebas de PRESion, Spanish for "Well Test Analist") a computerized expert system developed to analyze interference tests in homogeneous reservoirs. ANAPPRES is user friendly, requires essentially no experience on the part of the analist, eliminates subjectivity, can handle complex cases and large data sets, and completes the analysis of even the most complex cases, including plotting the results, in one run. In the current version ANAPPRES can analyze interference tests including 1 active well and an arbitrary number (as currently implemented, up to 20) observation wells. The user can be a beginner: the only requirement is that he (she) can create computerized files with the test data, for input. If prompted by the user, ANAPPRES explains how and why it arrived at the current conclusion(s). This feature has obvious didactic advantages for non-expert users and provides verification capabilities for expert analists. These characteristics of ANAPPRES were obtained applying artificial inteligence techniques, mathematical models, optimization techniques, heuristic knowledge and graphics software.

HARDWARE AND SOFTWARE

ANAPPRES was developed and is currently used in a VAX-11/780, a computer system widely used in universities and R&D institutions. For input-output it uses the graphics terminal Digital VT241, and for hardcopy output the Digital LA210 Letterprinter and the Hewlett Packard HP-7585B pen plotter.

For intercomputer portability the software is written in Fortran 77.

ARCHITECTURE OF ANAPPRESS

The architecture of ANAPPRES is represented in Fig. 1. There are 5 main modules, with 4 of them (the User Interface, the Computational Module, the Knowledge Base and the Explanatory Module) linked to the central Inference Engine which drives the analysis. The functions of the different modules are described below.

The user must provide 2 types of data files, corresponding respectively to the active well, and the observation wells. These files are created with a word processing (editor) program and must conform to specified formats. The data files are read directly from the Computational Module.

Having created the data files, the user can run ANAPPRES. This is an interactive process in which the program prompts the user for information and instructions. The interaction is driven by the User Interface module.

User Interface. Its main goal is to provide a friendly environment for communication with the user. Communication proceeds via questions and answers. The main functions of this module (Fig. 1) are to generate menus, to display diagnostics and numerical results, to generate graphics, and to display explanations. Figs. 2-5 illustrate the presentation of menus, results, graphics and explanations, respectively (Note: the single-well test option depicted in Fig. 2 is not implemented in ANAPPRES's current version). A general

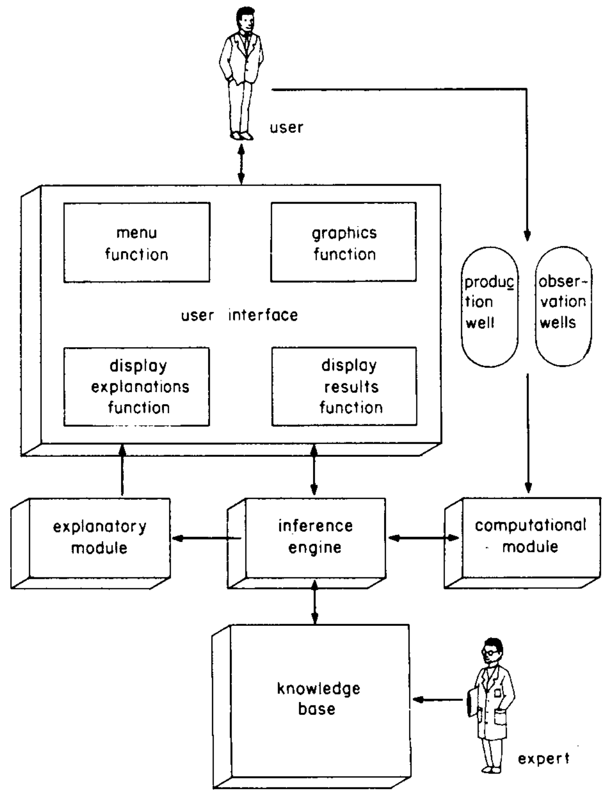


Fig. 1. Architecture of ANAPPRES.

graphics package, developed in-house (Rodriguez et al., 1987), is used by the Graphics function.

Computational module. This is a modified version of the program ANALYZE (Mc Edwards and Benson, 1981), developed for analysis of interference tests in single (liquid) phase, homogeneous, isotropic reservoirs. ANALYZE assumes a constant-thickness, infinite, radial reservoir, and models the active well as a totally penetrating line source. This module determines reservoir parameters by minimizing the differences between observed and model pressure histories. Pressure histories are modeled with the Theis (1935) solution. The minimization is achieved by means of a non-linear least-squares routine (Beals, 1966), which requires initial guesses of reservoir parameters for its use. A Chi-square statistic, normalized to the observed pressures, provides a quantitative measure of the goodness of the fit.

The modifications to the original code were designed to obtain a good coupling with the architecture of ANAPPRES. They include refreshing the memory in succesive calls to this

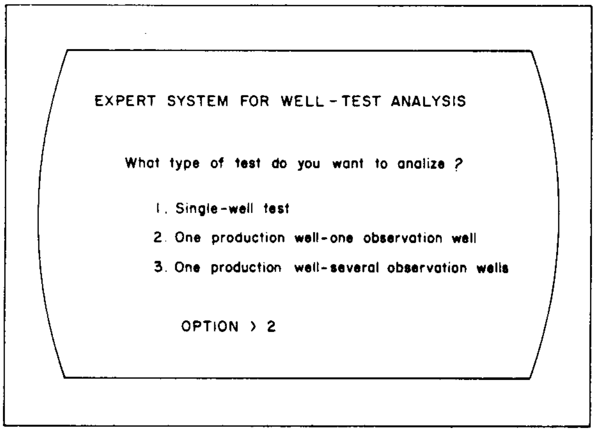


Fig. 2. Example of a display generated by the Menu Function.

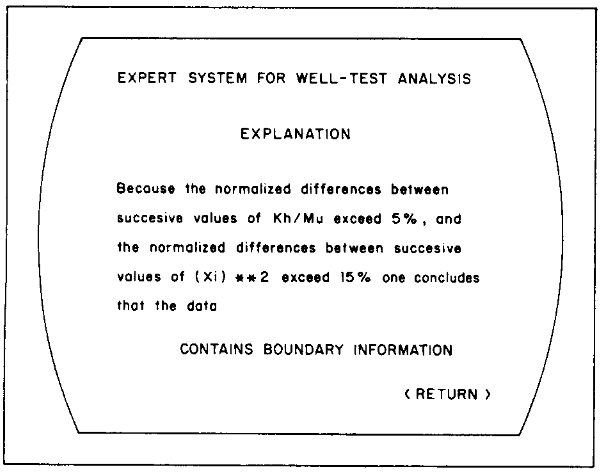


Fig. 3. Example of a screen generatred by the Display Explanations function.

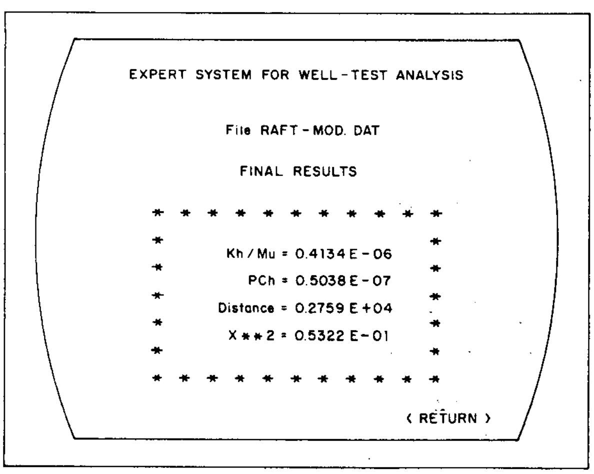


Fig. 4. Example of a screen generated by the Display Results function.

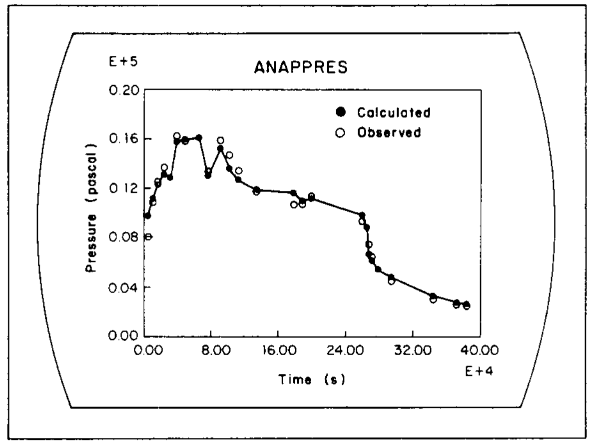


Fig. 5. Example of a screen generated by the Graphics function.

module, automatic handling of error conditions, and the inclusion of criteria to decide whether a run with given reservoir parameter initial guesses will converge (a time-saving feature).

<u>Knowledge Base</u>. It contains the knowledge necessary to perform the analysis of interference tests. This knowledge includes quantitative criteria to decide whether a particular fit is acceptable, how to diagnostic whether there is a hidrologic boundary and its type, what initial guesses to use in order to start the Computational Module, etc. For example, Fig. 6 is a map in the transmissivity-storativity plane, illustrating 16 trigger points, and the corresponding areas of convergence, that ANAPPRES will use as initial guesses to start the Computational Module, if the user chooses not to provide an initial guess, or if the initial guess provided by the user failed to promote convergence. The Knowledge Base is organized in production rules, with the well-known IF-THEN format (Arellano, 1987).

<u>Inference Engine</u>. This module drives the analysis of the test, on the basis of its built-in information, the options selected and the input data given by the user, the partial results provided by the Computational Module, and the information provided by the Knowledge Base. The Inference Engine controls the operation of the Computational Module, and gets results, such as Chi-square and reservoir parameter values, from it. With this information, the Inference Engine interacts with the Knowledge

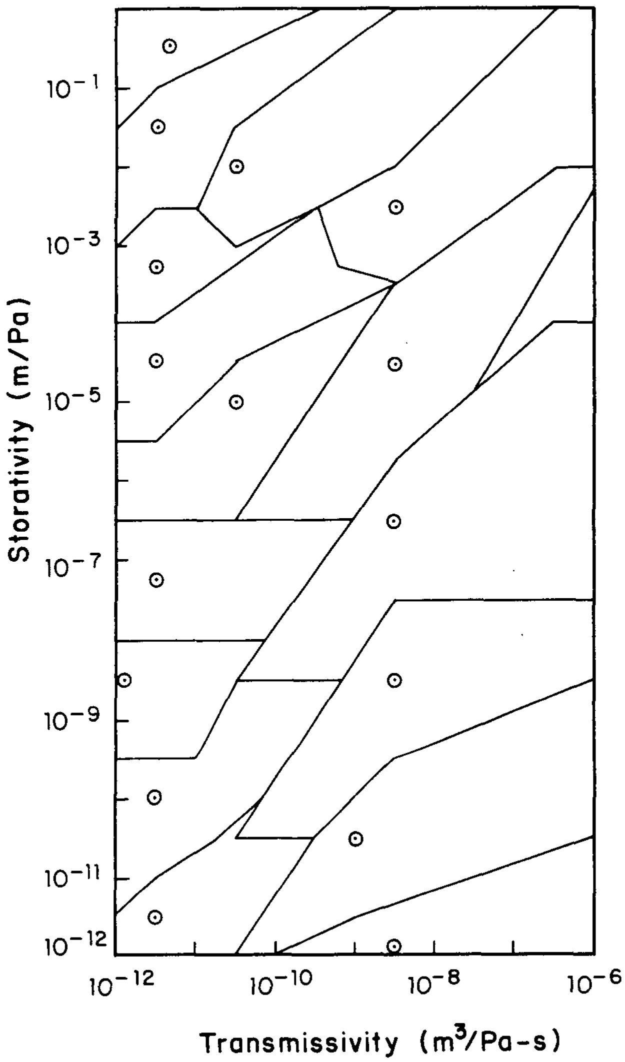


Fig. 6. Trigger points, and the corresponding convergence regions, used by ANAPPRES as initial guesses to start the Computational Module if the user chooses not to provide initial guesses, or if the initial guesses provided by the user failed to promote convergence.

Base in order to reach conclusions. Every time the Inference Engine reaches a conclusion, it commands the User Interface to display it in the screen of the VT241 terminal and ask the user if an explanation is requested, sets flags that enable the Explanatory Module to support the conclusion(s), and commands the User Interface to ask whether a graphic display of the resulting fit is requested. These interactions are repeated as necessary (several to many times, depending on the complexity of the case under analysis) in each run of ANAPPRES.

Explanatory Module. It contains preformatted explanations for all the diagnostics and conclusions ANAPPRES can reach. These 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 Explanatory Module passes on the corresponding explanation to the User Interface, which displays it through its Display Explanation function (Fig. 1).

METHOD OF ANALYSIS

Unlike previous computerized analysis techniques, ANAPPRES performs a totally automatic interference tests analysis in a single run. That is, it finds out whether there is evidence of a hydrologic boundary in the test data and determines its type, computes storativity and transmissivity values for each observation well, and, if possible, computes storativity and transmissivity values averaged over the participating wells, and distance and angle from an arbitrary origin to the hydrologic boundary. Furthermore, it can provide, on request, screen or hardcopy plots of the model fits obtained in the process.

Fig. 7 briefly illustrates the method of analysis. For ech observation well ANAPPRES determines whether the corresponding data indicate the existence of a boundary, and if there is one, its type (either no-flow or constant-pressure). At this stage, estimates of the storativity and transmissivity associated with the well are obtained; these are taken as final results for the well if no boundary is detected. If a boundary is detected, the values of the transmissivity, storativity and distance of the boundary to the origin are simultaneously determined, using the estimates of transmissivity and storativity as initial guesses. This is sequentially done for each and all the observation wells participating in the test.

If 2 wells detected a boundary, a final analysis simultaneously including both wells is performed to obtain the average values of storativity and transmissivity, the distance of the boundary to the origin and β, the angular location of the boundary. However, in this case β is not uniquelly determined and the true angular location could be $2\pi-\beta$. If

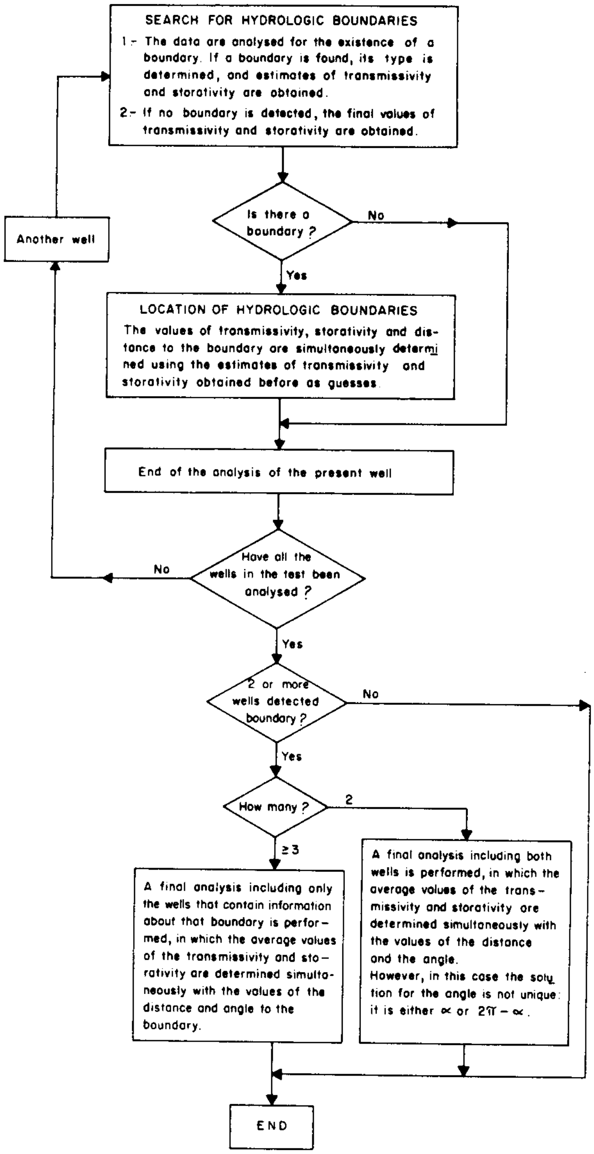


Fig. 7. Method of analysis used by ANAPPRES.

more than 2 wells detected a boundary, a final analysis simultaneously including all these wells is performed to obtain storativity, transmissivity, distance and angle; in this case the angle is uniquely determined.

VALIDATION

At the time of this writting ANAPPRES V1.0 had been validated against 3 problems with known solutions. They include: (a) a constant-flowrate match of the Theis curve, modeling the simplest interference case in an infinite reservoir (Mc Edwards and Benson, 1981); (b) a two-well (active and observation), constant-flowrate production interference test in the Raft River, Idaho, geothermal project that detected a no-flow boundary (Narasimhan and Witherspoon, 1977); and (c) a multiwell, highly-variable flowrate, injection interference test in a shallow groundwter aquifer under consideration for an aquifer thermal energy storage project (Mc Edwards and Benson, 1981). In all three cases ANAPPRES obtained the correct diagnostics and quantitative results, whether or not initial guesses were provided by the user. In case (a), where the synthetic "data" are noiseless and no deviations from the idealized reservoir model exist, the results were exactly coincident with those of the original source. In case (b), in which the original analysis was done using the type-curve graphical technique, with its unavoidable subjectivity, the differences were about 7%. In case (c), in which the original analysis was performed with ANALYZE in a vastly different computer system, the numerical results differed by about 4%. These differences are totally negligible for all practical purpouses.

For brevity, only the analysis of case (c), the most difficult by far, is illustrated here. Fig. 8 presents the relative locations of the 5 wells. Fig. 9 displays the highly variable injection flowrate. Figs. 10-13 illustrate the well by well search for hidrologic boundaries. Figs. 14-17 show the results of the simultaneous determinaton of transmissivity, storativity and distance of the boundary, well by well. And Fig. 18 presents the results of the final analysis, that includes all the wells simultaneously.

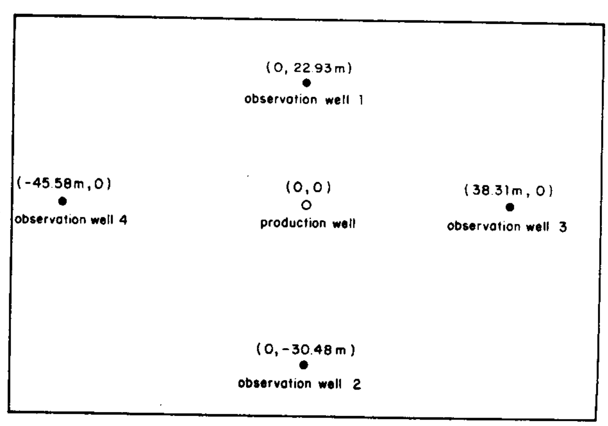


Fig. 8. Relative locations of the wells in case (c) (after Mc Edwards and Benson, 1981).

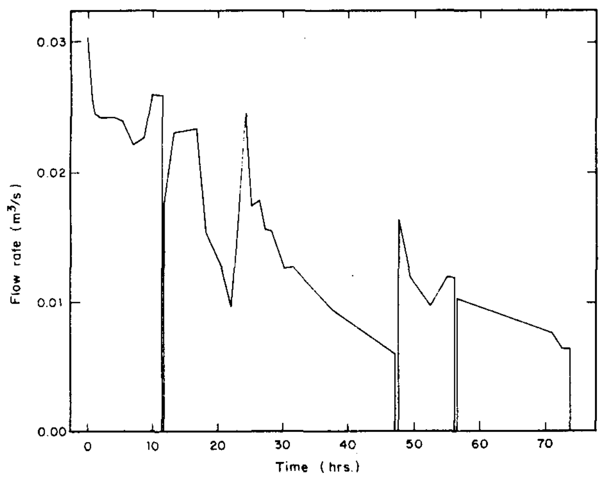
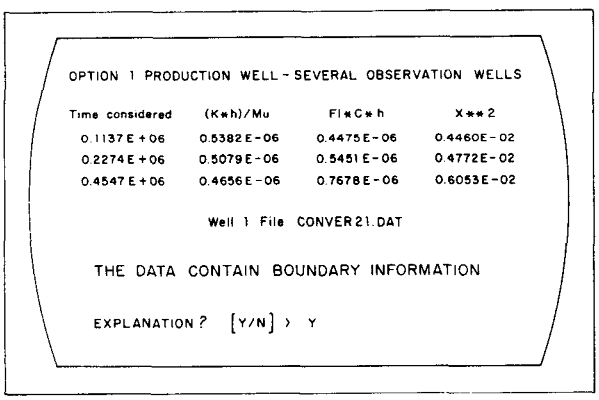


Fig. 9. Highly variable injection flowrate for case (c) (after Mc Edwards and Benson, 1981).



OPTION 1 PRODUCTION WELL - SEVERAL OBSERVATION WELLS

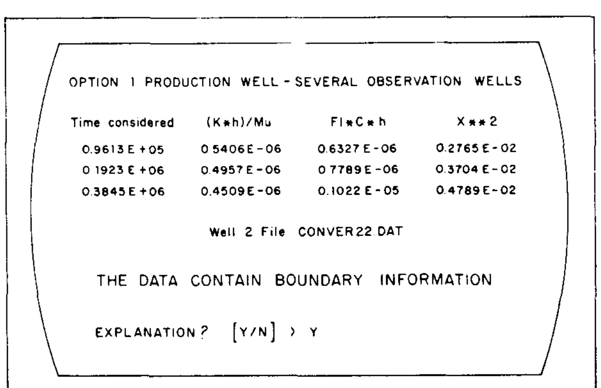
Time considered	(K*h)/Mu	Fl*C*h	X**2
0.1137 E +06	0.5382 E-06	0.4475 E-06	0.4460E-02
0.2274 E +06	0.5079 E-06	0.5451 E-06	0.4772E-02
0.4547 E +06	0.4656 E-06	0.7678 E-06	0.6053E-02

Well 1 File CONVER21.DAT

THE DATA CONTAIN BOUNDARY INFORMATION

EXPLANATION ? [Y/N] > Y

Fig. 10. Results of the search for hydrologic boundary for well #1 in case (c).



OPTION 1 PRODUCTION WELL - SEVERAL OBSERVATION WELLS

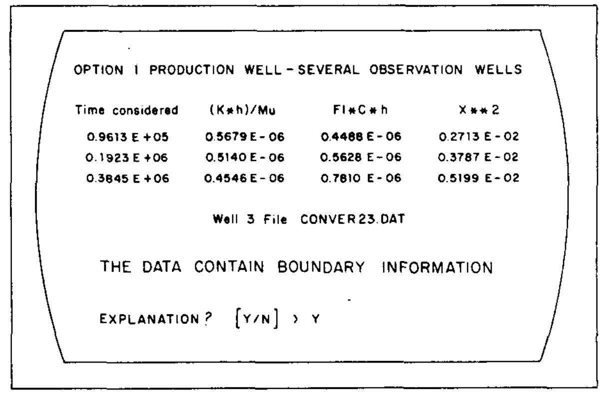
Time considered	(K*h)/Mu	Fl*C*h	X**2
0.9613 E +05	0.5406E-06	0.6327 E-06	0.2765 E-02
0.1923 E +06	0.4957 E-06	0.7789E-06	0.3704 E-02
0.3845 E +06	0.4509E-06	0.1022 E-05	0.4789 E-02

Well 2 File CONVER22 DAT

THE DATA CONTAIN BOUNDARY INFORMATION

EXPLANATION ? [Y/N] > Y

Fig. 11. Results of the search for hydrologic boundary for well #2 in case (c).



OPTION 1 PRODUCTION WELL - SEVERAL OBSERVATION WELLS

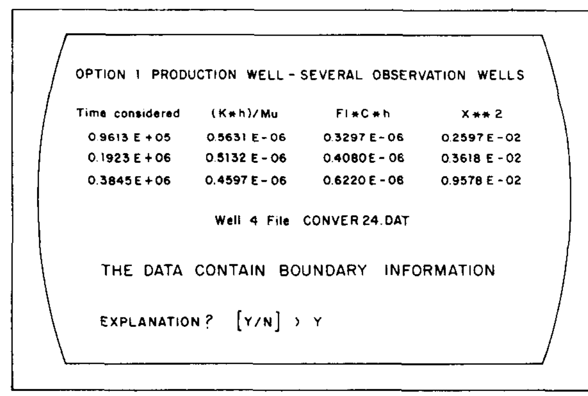
Time considered	(K*h)/Mu	Fl*C*h	X**2
0.9613 E +05	0.5679 E-06	0.4488 E-06	0.2713 E-02
0.1923 E +06	0.5140 E-06	0.5628 E-06	0.3787 E-02
0.3845 E +06	0.4546 E-06	0.7810 E-06	0.5199 E-02

Well 3 File CONVER23.DAT

THE DATA CONTAIN BOUNDARY INFORMATION

EXPLANATION ? [Y/N] > Y

Fig. 12. Results of the search for hydrologic boundary for well #3 in case (c).



OPTION 1 PRODUCTION WELL - SEVERAL OBSERVATION WELLS

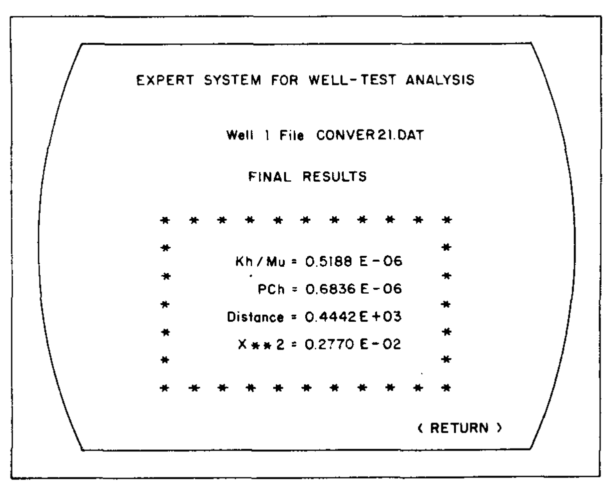
Time considered	(K*h)/Mu	Fl*C*h	X**2
0.9613 E +05	0.5631 E-06	0.3297 E-06	0.2597 E-02
0.1923 E +06	0.5132 E-06	0.4080E-06	0.3618 E-02
0.3845 E +06	0.4597 E-06	0.6220 E-06	0.9578 E-02

Well 4 File CONVER24.DAT

THE DATA CONTAIN BOUNDARY INFORMATION

EXPLANATION ? [Y/N] > Y

Fig. 13. Results of the search for hydrologic boundary for well #4 in case (c).



EXPERT SYSTEM FOR WELL-TEST ANALYSIS

Well 1 File CONVER21.DAT

FINAL RESULTS

Kh / Mu = 0.5188 E-06

PCh = 0.6836 E-06

Distance = 0.4442 E+03

X ** 2 = 0.2770 E-02

< RETURN >

Fig. 14. Final results for well #1, case (c).

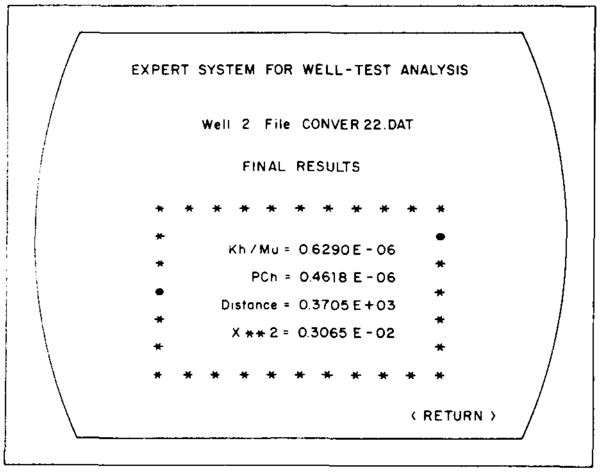


Fig. 15. Final results for well #2, case (c).

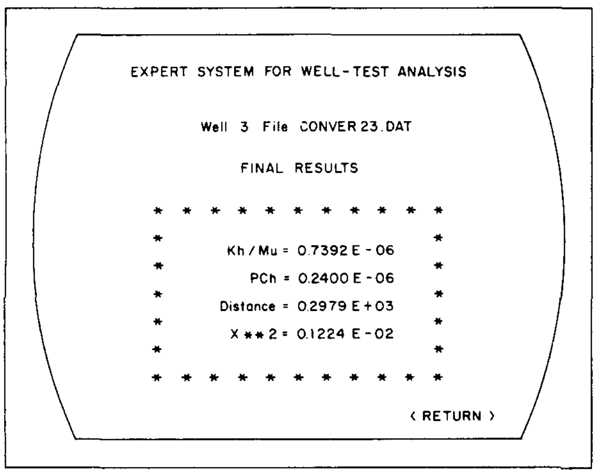


Fig. 16. Final results for well #3, case (c).

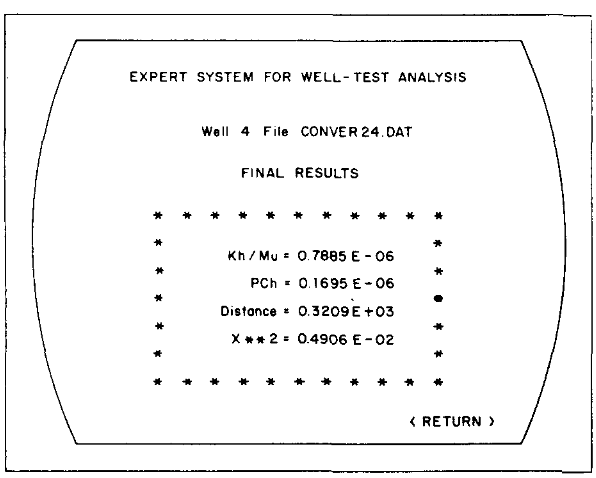


Fig. 17. Final results for well #4, case (c).

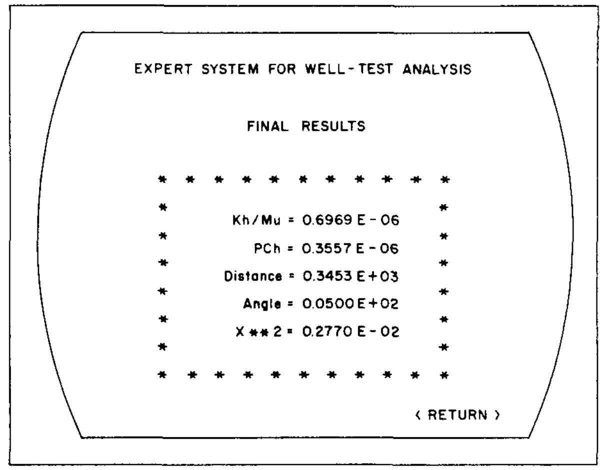


Fig. 18. Final results, averaged over the observation wells, for case (c).

CONCLUSIONS AND FUTURE WORK

We have developed and validated the first version of a computerized expert system capable of analyzing constant- and variable-flowrate interference tests, in which there is one active well and an arbitrary number of observation wells, in liquid-saturated homogeneous reservoirs. The main advantages of this system are that it is user friendly, requires essentially no experience on the part of the analist, eliminates subjectivity associated with earlier techniques of analysis, can handle complex cases and large data sets, completes the analysis of even the most complex cases (including plotting the results) in one run, and is significantly faster than a human expert.

The next version of ANAPPRES, which is already in an advanced stage of development, will include, in addition to the current capabilities, the possibility of analyzing interference tests including an arbitrary number of active wells, and several lesser upgrades. We are also working on the capability to analyze single-well pressure tests.

ACKNOWLEDGEMENTS

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