

ANAPPRES V2.0: A COMPUTERIZED EXPERT SYSTEM
FOR WELL-TEST ANALYSIS

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ABSTRACT

This paper presents ANAPPRES V2.0, the second version of a computerized expert system that interprets data of constant and variable-flowrate interference tests in which there are an arbitrary number of production wells and an arbitrary number of observation wells. From the analysis, the transmissivity (kh/y), storativity (S_h), and hydrologic boundaries (existence, type and location) are obtained. ANAPPRES successfully couples a mathematical model, an optimization technique and heuristic knowledge, an unusual combination rarely found in published expert systems. The main advantages of ANAPPRES as compared to standard methods, are: (1) it can analyze variable flowrate interference tests; (2) it can obtain 4 to 5 parameters (transmissivity, storativity, type of boundary, distance and angle to boundary) in one computer run; (3) it is considerably faster than a human expert in completion of the job and (4) allows analysis of well tests including an arbitrary number of observation wells and an arbitrary number of production wells.

INTRODUCTION

For interference test analysis, a type-curve graphical technique (e.g., Earlougher, 1977) has been the standard of the trade for many years. 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; McEdwards 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 requires extensive experience on the part of the analyst.

This work describes ANAPPRES V2.0 (ANALizador de Pruebas de PRESion, Spanish for "Well Test Analyst") 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 analyst, eliminates subjectivity, can handle complex cases and large data sets. In the current version ANAPPRES can analyze interference tests in which there are an arbitrary number of production wells and an arbitrary number of observation wells. The user can be a beginner: the only requirement is that he (she) can create files, with the test data, for input. If is required by the user, ANAPPRES can explain how and why it arrived at

the current conclusion. This feature has didactic advantages for non-expert users, provides verification capabilities for expert analysts and increases confidence in the expert system. These characteristics of ANAPPRES were obtained applying artificial intelligence techniques, mathematical models, optimization techniques, heuristic knowledge and graphics software.

ANAPPRES was developed on a VAX-11/7B0 computer system. For input-output it uses the terminal Digital VT241, and for hardcopy output the Digital LA210 Letterprinter and the Hewlett Packard HP-7585 pen plotter. ANAPPRES is written in FORTRAN 77.

ARCHITECTURE OF ANAPPRES

The architecture of ANAPPRES is presented 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.

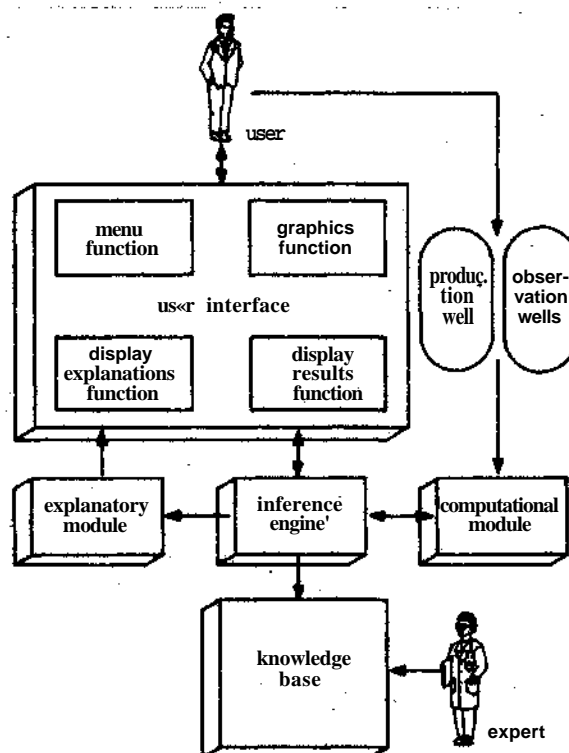


Fig. "1i Architecture of ANAPPRES.

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User Interface. Its main goal is to provide a friendly environment for communication with the user. The main functions of this module are to generate menus, to display diagnostics and numerical results, to generate graphics, and to display explanations.

Computational module. This is a modified version of the program ANALYZE (Mc Edwards and Benson, 1981). The modifications to the original code include refreshing the memory in successive calls to this module, automatic handling of error conditions, and the inclusion of criteria to decide whether a run with given reservoir parameter initial guesses will converge.

ANALYZE was developed for analysis of interference tests in single (liquid) phase, homogeneous, isotropic reservoirs. This program determines reservoir parameters by minimizing the differences between observed and calculated pressure histories. Pressure histories are calculated with the Theis solution. The minimization is achieved by means of a non-linear least-squares routine. A Chi-square statistic, normalized to the observed pressures, provides a quantitative measure of the goodness of the fit.

Knowledge Base. The Knowledge Base is organized in production rules, with the well-known IF-THEN format (Arellano, 1987). It contains the knowledge necessary to perform the analysis of interference tests. This knowledge includes quantitative criteria to decide whether there is a hydrologic boundary and its type, what initial guesses to use in order to start the Computational module, etc. For example Fig. 2 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. This map was obtained by the analysis of the solution domain of 230 synthesised well tests.

Inference Engine. This module drives the analysis of the test, on the basis of 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 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.

Explanatory Module. It contains preformatted explanations for all the diagnostics and conclusions that 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 the corresponding explanation to the User interface, which displays it through its Display Explanation function (Fig. 1)

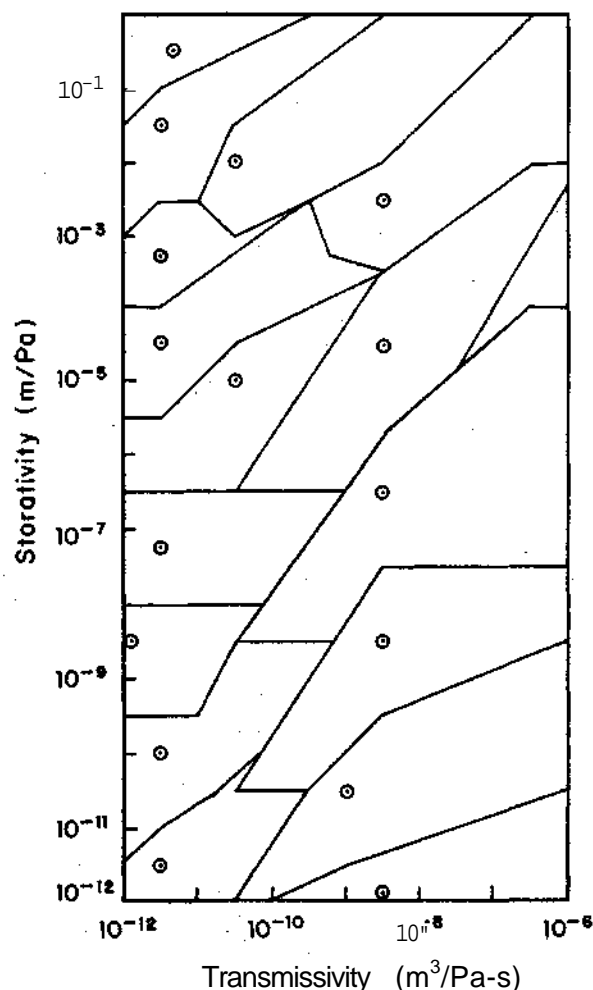
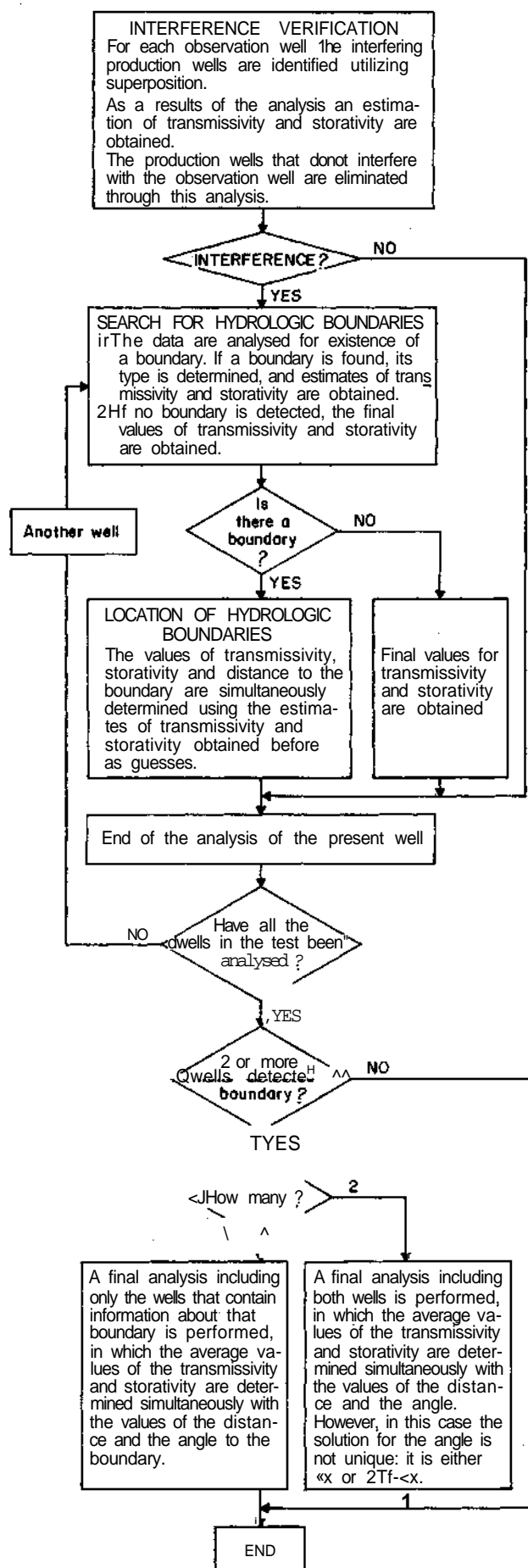


Fig. 2: Trigger points used by ANAPPRES as initial guesses to start the Computational Module.

METHOD OF ANALYSIS

ANAPPRES performs a totally automatic interference tests analysis in a single run. That is, it finds out if there is evidence of a hydrologic boundary in the test data and determines its type, computes storativity and transmissivity values, and distance and angle from an arbitrary origin to the hydrologic boundary.

Fig. 3 illustrates the method of analysis. The analytical process is divided internally into three stages. These are: interference verification, search for hydrologic boundaries and location of hydrologic boundaries. ANAPPRES determines for each observation well the interfering production wells, using superposition. After that, for each observation well ANAPPRES determines if 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. This is sequentially done for each and all the observation wells participating in the test.



If two wells detect 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 θ , the angular location of the boundary. However, in this case θ is not uniquely determined and the true angular location could be $2\pi - \theta$. If more than two wells detect 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 writing ANAPPRES V2.0 had been validated against a number of published and unpublished problems with known solutions. The former include: (a) a constant-flowrate match of the Theis curve, modeling the simplest interference case in an infinite reservoir (McEdwards 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); (c) a constant-flowrate production interference test between wells 6-2 and 6-1 at the East Mesa geothermal field that detected a constant-pressure boundary (Narasimhan et al., 1977); (d) a constant-flowrate production interference test between wells 31-1 and 38-30 at the East Mesa geothermal field that detected a no-flow boundary (Narasimhan et al., 1977); (e) a multiwell, highly-variable flowrate, injection interference test in a shallow groundwater aquifer under consideration for an aquifer thermal energy storage project (McEdwards and Benson, 1981); and (f) a multiple-production-well interference test in a geothermal reservoir currently being used for electric power generation (McEdwards y Benson, 1981).

In all cases ANAPPRES obtained the correct diagnoses and quantitative results, whether or not initial guesses were provided by the user. Quantitative results obtained by the expert system agreed with previous results to better than 10 %. These differences are negligible for all practical purposes.

CONCLUSIONS AND FUTURE WORK

We have developed and validated the second version of a computerized expert system capable of analyzing constant and variable flowrate interference tests, in which there are an arbitrary number of production wells 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 analyst, 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 single-well pressure tests.

Fig. 3: Method of analysis used by ANAPPRES.

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REFERENCES

- ARELLANO, V.M. (1987): Desarrollo de un sistema experto para el analisis de pruebas de presion. M.S. Thesis, Universidad Autonoma del Estado de Morelos Cuernavaca, Mor., México.
- EARLOUGHER, R.C. (1977): Advances in well test analysis. Society of Petroleum Engineers Monograph, 5.
- EARLOUGHER, R.C. and KERSCH, K.M. (1972): Field examples of automatic transient test analysis. Paper SPE-3363, presented at the Society of Petroleum Engineers 46th Annual Fall Meeting, New Orleans, Oct. 4-7
- McEDWARDS, D.G. and BENSON, S.M. (1981): User's manual for ANALYZE, a multiple-well least squares matching routine for well-test analysis. Report LBL-10907 Lawrence Berkeley Laboratory.
- NARASIMHAN, T.N. and WITHERSPOON, P.A. (1977): Reservoir evaluation tests RRGE-1 and RRGE-2, Raft River geothermal project, Idaho. LBL-5958, Lawrence Berkeley Lab.
- NARASIMHAN, T.N. McEDWARDS D.G. and WITHERSPOON, P.A. (1977): Results of reservoir evaluation tests 1976, East Mesa geothermal field, California. LBL-5973 Lawrence Berkeley Laboratory.