PROCEEDINGS, Seventeenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 29-31, 1992
SGP-TR-141

PRODUCTION DIAGNOSTICS OF GEOTHERMAL WELLS BY MEANS OF A COMPUTERIZED EXPERT SYSTEM

Victor M. Arellano, Eduardo R. Iglesias,
Gregorio San Román and David Nieva

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

ABSTRACT

Diagnostic of production problems in geothermal wells is a complex inferential task, which requires considerable knowledge of its possible causes, careful assessment of (sometimes bewildering) multidisciplinary evidence, and, of course, enough experience. These characteristics make this task a good candidate for a computerized expert system. On this conviction, we have developed the first version of WELL_DR, an expert system for geothermal-well production diagnostics. Though still in a rapid stage of evolution, this expert system already provides a convenient and useful tool for geothermal field development, operation and management.

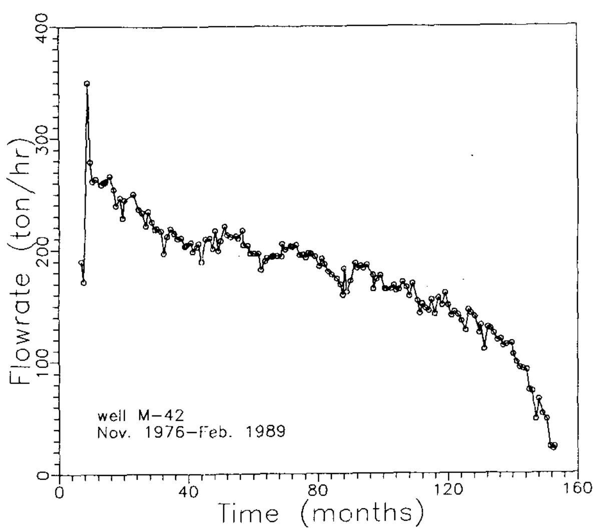

Fig. 1 Flowrate history of Cerro Prieto well M-42.

INTRODUCTION

Energy production is the ultimate goal of any geothermal development. Energy production is accomplished through wells. Wells act as conduits for production of fluid and heat, and provide crucial information about the reservoir (or reservoirs) they intersect. For these reasons, wells are critical components of exploited geothermal fields.

Production of geothermal wells varies with time. This may be due to "normal" or to "pathological" causes. Normally, well production diminishes with time due, mainly, to exploitation-induced reservoir pressure drawdown. Figures 1-5 show an example of this type of behavior. They also demonstrate the type of information often available about the production history of a geothermal well.

On the "pathological" side, several causes may impair the capacity of a well as a conduit. For example, mechanical damage of its internal casing (piping), scaling by minerals precipitated from the produced fluid, partial occlusion by measuring or drilling equipment accidentally left in the well, etc. Production

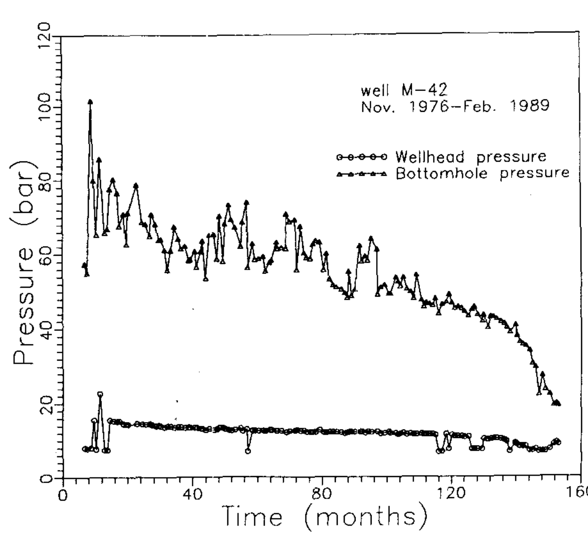

Fig. 2 Pressure history of Cerro Prieto well M-42.

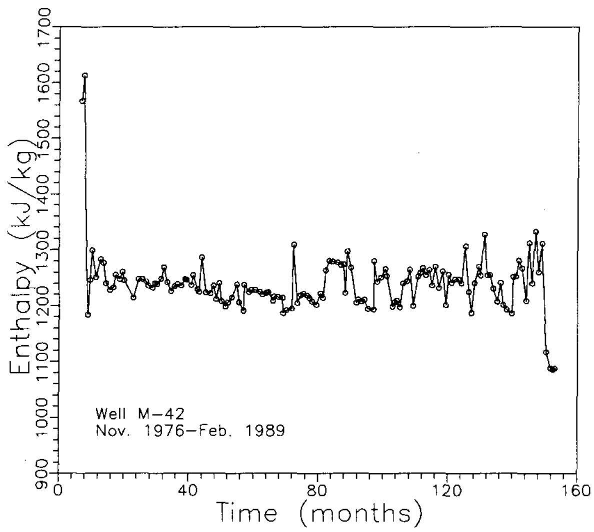

Fig. 3 Enthalpy history of Cerro Priero well M-42.

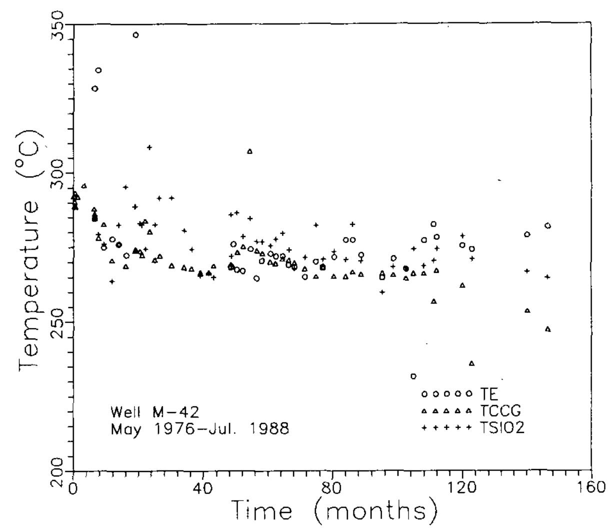

Fig. 5 Geothermometric temperature histories of Cerro Prieto well M-42.

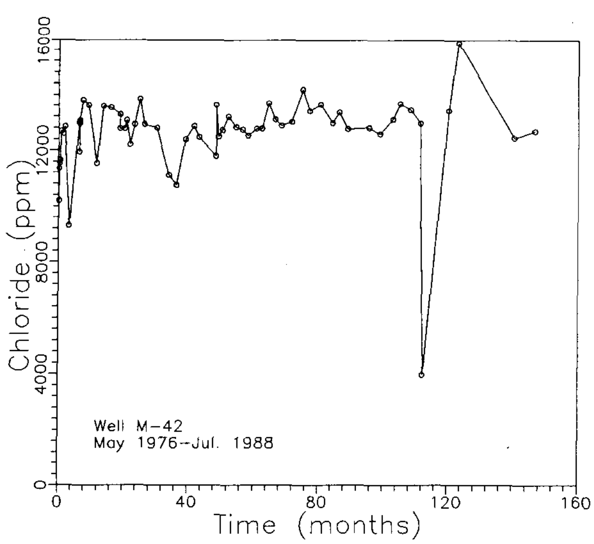

Fig. 4 Chloride history of Cerro Prieto well M-42.

may also be influenced by many "pathological" causes affecting the reservoir (or reservoirs) intersected by the well. These include invasion by colder waters from neighboring aquifers or from injection of spent brines, permeability reduction near the well by mineral deposition triggered by boiling or by mixing of different fluids, production from two or more reservoirs having fluids with different enthalpies or chemical compositions, etc., and combinations of these. Often some of these causes affect production not only at the reservoir level, but also by impairing the capacity of the well as a conduit (e.g., scaling of the well piping induced by the arrival of a cold front).

From a practical point of view, production problems can be classified into those that affect only one well, and those that affect some or all the wells in a certain area. In economic terms, the latter are obviously more important. In general, production problems with the capacity to affect a significant area, or even a whole field, can be detected early in one or a few wells, before much damage is done. Early detection allows, in many cases, implementation of remedial actions to correct the causes of the problem, or to delay as much as possible their effects on production. Though usually less important, diagnostic of individual well production problems is also economically significant. For these reasons, diagnostic of production problems in wells is a crucial capability to have, for successfully managing geothermal fields.

Diagnostic of production problems in geothermal wells is a complex inferential task, which requires considerable knowledge of its possible causes, careful assessment of (sometimes bewildering) multidisciplinary evidence, and, of course, enough experience. These characteristics make this task a good candidate for a computerized expert system. On this conviction, we have developed the first version of WELL_DR, an expert system for geothermal-well production diagnostics.

We are unaware of any previous similar work.

The next section describes the architecture of WELL_DR, the following section presents application examples and the last section presents the conclusions.

ARCHITECTURE OF WELL_DR

For prototyping and developing WELL_DR we chose a commercial, generalized expert system development package (a shell, in the parlance of the trade). For practical reasons (cost, hardware availability, installed base, portability), we adopted a shell that runs on personal computers under the DOS operative system. Should WELL_DR grow beyond reasonable response time running in DOS platforms, it could be easily ported to platforms with greater computational resources, because there are versions of the adopted shell that run in workstations and minicomputers under the UNIX and VMS operative systems.

Like most other expert system implementations, this shell offers three main components: an inference engine, a user interfase and a knowledge base.

Inference engine

The inference engine drives the diagnostic process. It may operate either in forward or backward chaining mode. Normally, the inference engine test rules by looking for the first rule with the first final (as oposite to intermediate) conclusion (final conclusions = diagnostics are assigned an order by the developer) in its THEN or ELSE part, and tests the IF condition of that rule. If any information on 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 final conclusion, etc., until it has gone through all of the rules. The process is then repeated for those rules relevant to the second final conclusion, third final conclusion, etc., until the list of final conclusions is completely tested. If a rule is not relevant to any final conclusion, or does not assign values to a variable whose value is displayed at the end of a run, it will not be used.

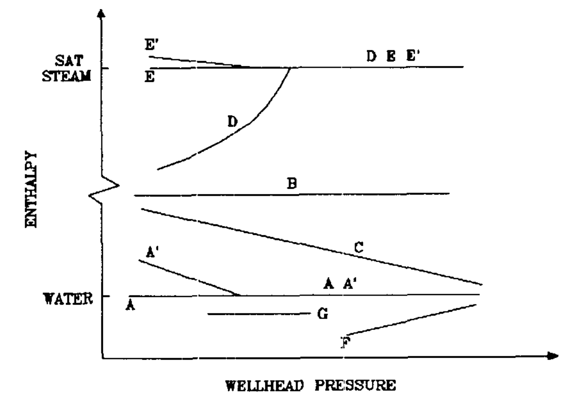

Fig. 6 Output curves: form of the variation of enthalpy with wellhead pressure (After Grant et al., 1982).

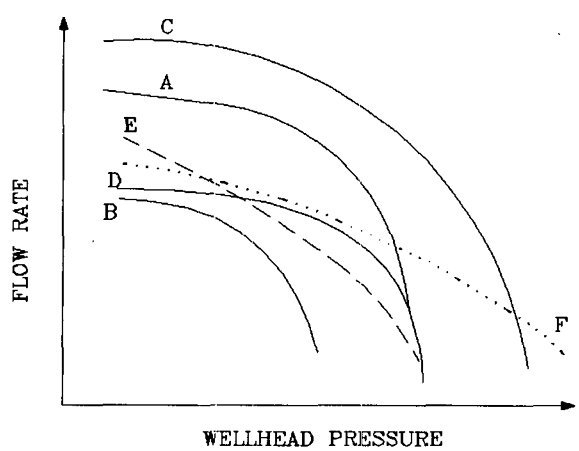

Fig. 7 Output curves: form of the variation of mass flow with wellhead pressure (After Grant et al., 1982).

User interfase

The user interfase implements dialogue boxes, in which WELL_DR asks for the necessary information. Some dialogue boxes include technical graphs to help the user decide what type of trend is present in his data. Figures (6-7) illustrate some technical graphs already in use. At any stage of the process, the user can ask why a particular conclusion was reached, and get the corresponding explanation. If more than one diagnostic is possible, the program will provide a list of the possible diagnostics arranged in order of probability.

Knowledge base

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. There are three choices to assign probabilities. One of them allows computation of dependent and of independent probabilities, at will. This is the choice adopted for WELL_DR.

Currently, our knowledge base includes more than 65 rules. The number of final conclusions (diagnostics) that can be reached is 24.

Our knowledge base was compiled from our own and other people's experience. Main contributions came from Arellano et al. (1990), Arellano et al. (1991), Grant et al. (1981), Grant et al. (1982), Nathenson (1975), Truesdell et al. (1979), Truesdell et al. (1989).

Whenever possible, we tried to test the final conclusions (diagnostics) by more than one independent line of evidence. To that end, the knowledge base includes three main topics:

Initial state of the well

Production tests

Production history

In the cases where the diagnostic is backed by more than one independent line of evidence, the probability of the diagnostic is computed correspondingly.

APPLICATION EXAMPLES

This example deals with well M-35 from the Cerro Prieto, Mexico, geothermal field. Figures (8-12) illustrate production histories of this well.

This case was correctly diagnosed as "chemical breaktrough of cooler water", with a confidence of 9.4/10, from two independent rules:

RULE 22

IF [CHLORIDE DECREASES WITH TIME AND DISCHARGE ENTHALPY DECREASES WITH TIME]

THEN
[CHEMICAL BREAKTHROUGH OF COOLER WATER]

CONFIDENCE = 7/10

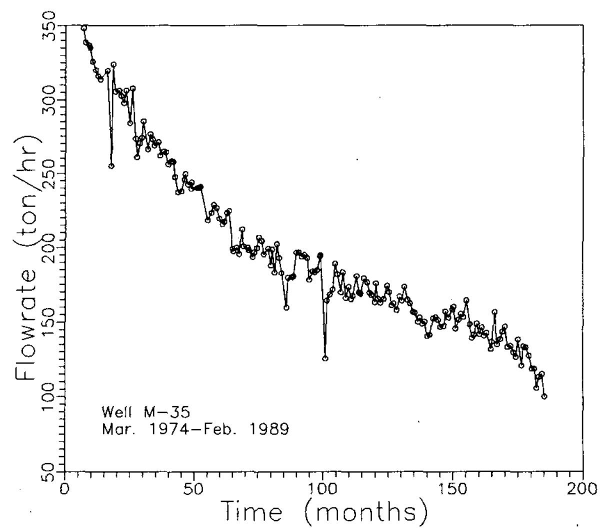

Fig. 8 Flowrate history of Cerro Prieto well M-35.

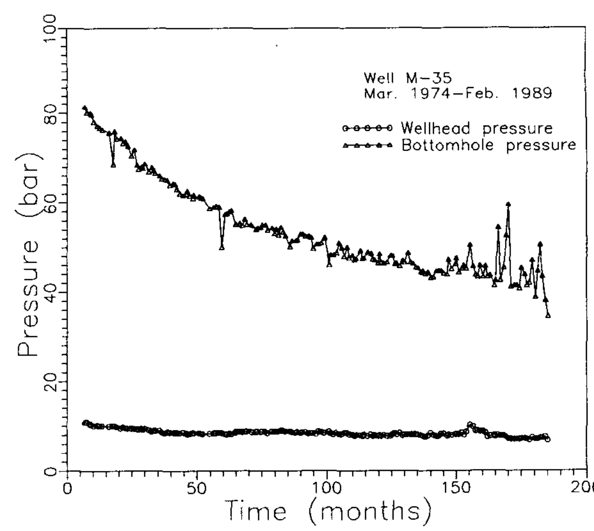

Fig. 9 Pressure history of Cerro Prieto well M-35.

RULE 23

IF [TE = TSIO2 > TCCG]

THEN
[CHEMICAL BREAKTHROUGH OF COOLER WATER]

CONFIDENCE = 7/10

Figures 10-11 indicate that the conditions of Rule 22 are met by this well, and Fig. 12 shows that the conditions of Rule 23 are also satisfied. Data plots like (8-12) must be available to the user running the diagnostic analysis, in order to answer the questions posed by WELL_DR.

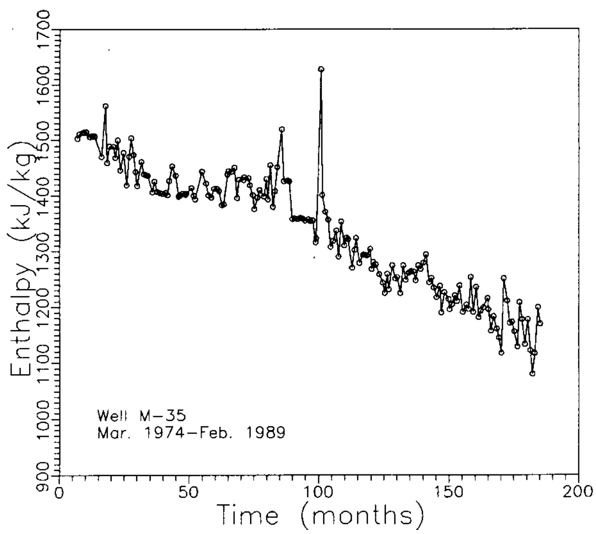

Fig. 10 Enthalpy history of Cerro Priero well M-35.

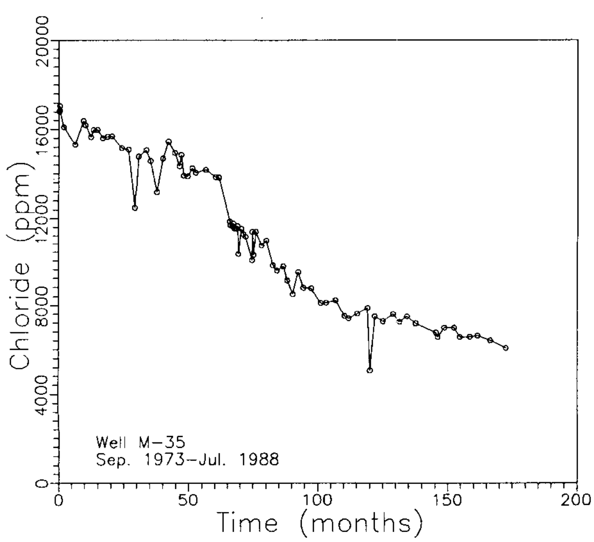

Fig. 11 Chloride history of Cerro Prieto well M-35.

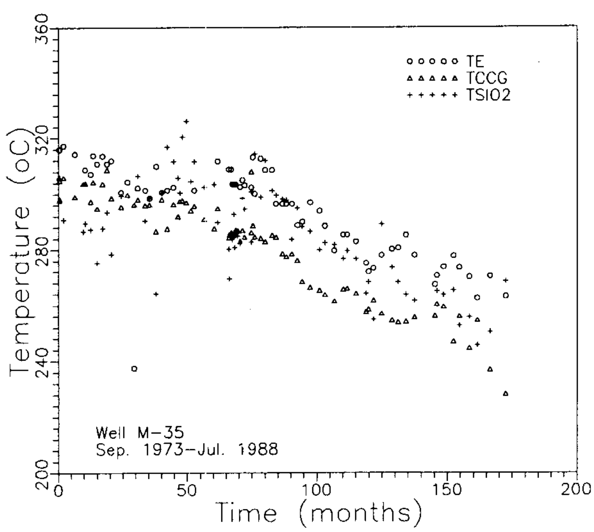

Fig. 12 Geothermometric temperature histories of Cerro Prieto well M-35.

The next example demonstrates the usefulness of the technical graphs presented by WELL_DR to the user, when trying to prove certain groups of rules. The user is asked to compare his data plots to those shown in the screen, and choose the option that best resembles his data. Thus, the user would compare Fig. 13 with Fig. 7, and choose A and D. WELL_DR would then conclude that there is scaling in the wellbore with confidence equal to 6/10. This conclusion would be correct: in June 1986 well M-109 from Cerro Prieto had to be reworked due to scaling.

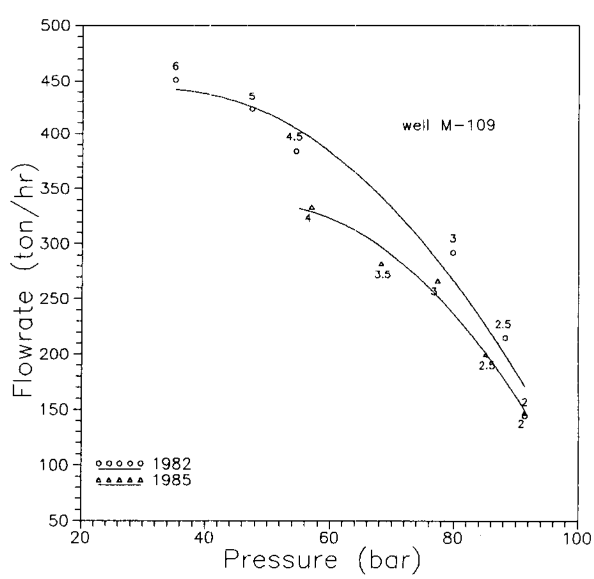

Fig. 13 Output curves of Cerro Prieto well M-109.

SUMMARY AND CONCLUSIONS

We have developed the first version of WELL_DR, an expert system for geothermal-well production diagnostics.

WELL_DR was implemented with a commercial, generalized expert system development package. It runs on personal computers under the MS-DOS operative system. Its knowledge base consists of IF-THE-ELSE type rules that include heuristic probabilities.

Interaction with the user is implemented via dialogue boxes, in which WELL_DR asks for the necessary information. Some dialogue boxes include technical graphs to help the user decide what type of trend is present in his data. The user can ask why a particular conclusion was reached, and get the corresponding explanation. If more than one diagnostic is possible, the program will provide a list of the possible diagnostics arranged in order of probability.

Though still in a rapid stage of evolution, this expert system already provides a convenient and useful tool for geothermal field development, operation and *management*.

REFERENCES

Arellano, V.M., Barragan, R.M., and Nieva, D., (1990), "Desarrollo de criterios de operación para minimizar problemas de obturación de la zona de alimentación de pozos de Cerro Prieto", Informe IIE/11/2730/I 02/F, Cuernavaca, Mor.

Arellano, V.M., Nieva, D., Barragan, R.M., and De Leon J., (1991), "Developments in geothermal energy in Mexico-Part thirty-seven. Procedure to diagnose production abatement problems in geothermal wells", Heat Recovery Systems & CHP, Vol. 11, No. 6, pp. 471-481.

Grant, M., Truesdell, A.H., and Mañon, A., (1981) "Production induced boiling and cold water entry in the Cerro Prieto geothermal reservoir indicated by chemical and physical measurements", Proceedings Third Symposium on the Cerro Prieto Geothermal Field, Baja California, México, San Francisco Ca., March 24-26, pp. 221-237.

Grant, M., Donaldson, I., and Bixley P., (1982), "Geothermal reservoir engineering", Academic Press, New York, pp. 137-144

Nathenson, M. (1975), "Physical factors determining the fraction of stored energy recoverable from hydrothermal convection systems and conduction dominated areas", U.S. Geological Survey Open-file Report 75-525, 51 p.

Truesdell, A.H., Mañon, A., Jimenez, E., Sanchez, A., and Fausto, J., (1979), "Geochemical evidence of drawdown in the Cerro Prieto geothermal field", Geothermics, Vol. 8, pp. 257-265.

Truesdell, A.H., Aunzo, Z., Bodvarsson, Alonso, J., and Campos, A., (1989), "The use of Ahuachapan fluid chemistry to indicate natural state conditions and reservoir processes during exploitation", Proceedings, Fourteenth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford Ca., January 24-26, pp. 273-278.