

Auxiliary System for Chemical and Production Data Analysis: ANAGEOT

Adriana Paredes-Soberanes*, Alfonso Aragon-Aguilar, Rosa M. Barragan, Victor M. Arellano, Siomara Lopez-Blanco

Instituto de Investigaciones Eléctricas, Reforma 113, Col. Palmira, Cuernavaca, Morelos, México CP 62490

Abstract— *This paper describes a computational tool developed to aid the analysis of chemical, isotopic and production data of geothermal wells. ANAGEOT is an interactive and user-friendly software that allows quickly and efficient manner, modification, retrieval and visualization of the wide amounts of data involved in the study of reservoirs. ANAGEOT optimizes time and resources, due to high quantity of historical data of most of the wells of various petroleum and geothermal fields which involve information sometimes of very long time periods. The system has the flexibility to work with different fields, considering a database for each one. A very important feature of this tool is that the reports, charts and graphs are generated in a way which can be edited at any time. Similarly these can be used as source files for other applications, because they are generated in wide commercial use applications such as Microsoft Word, Excel and Golden Grapher.*

Keywords— *Computational tool, Geochemical analysis, Geothermal wells, Information processing, Interactive software.*

I. INTRODUCTION

The analysis of chemical and production data of the wells is a task of great importance for the exploitation of geothermal reservoirs, allowing identify the main reservoir processes induced by extraction and eventual reinjection of fluid [1, 2]. The study of the behavior patterns of different geochemical parameters [3] (temperature estimations, vapor fraction of the reservoir, volumetric liquid saturation, etc.) and production [4, 5] (flow rate, pressure, enthalpy and bottom conditions) is useful in reservoir characterization [6, 7], the analysis of the parameters as function of time and its comparison with characteristic patterns [8], helps prevent contingencies that could affect field operations and impact on economic, and/or energy resource damages or losses to the environment [9]. The ANAGEOT (Geothermal Analysis) program was developed in order to facilitate analysis of information related to processes of geothermal systems [10]. It allows part of automated processing, which involves the application of

geochemical models and other disciplines so friendly and simple, thus optimizing time and resources in its realization. Furthermore, the system provides information in graphs and tables that can be integrated to different final reports. This paper describes this tool and some of the most representative applications. The tool has been developed and applied in different Mexican geothermal fields [6, 11]. The ANAGEOT program has shown to be a useful tool in processing the information, reviews, possible changes for updating, analysis and interpretation. The practical application of ANAGEOT is linked to the nature of the projects and the growth [12, 13] that some geothermal fields have had in recent years.

II. ANAGEOT DESCRIPTION

ANAGEOT is a tool based on client-server architecture (Figure 1), is constructed in the programming language Visual Basic 6 and as manager database My SQL Server (database management system relational data type). This application was developed on a computer HP Z210 Workstation, Intel Xeon processor with Windows 7 operating system and can be compatible OS Windows XP, 2000 and NT Workstation. The program uses as graphics software, Golden Grapher V8 or higher, and Microsoft Office Word and Excel for viewing reports. ANAGEOT is a multidisciplinary and interactive tool, effective for integration and support the study and analysis of the behavior of geothermal reservoirs [14]. It provides graphical and tabular representation of several calculations needed for the study, analysis and efficient interpretation of information of different geothermal fields.

2.1. Advantages of having ANAGEOT

The advantage of having this tool lies in disposing important information quickly and easily, which greatly contributes to saving time for review and processing, as well as generating charts and reports. In this way the efforts are being directed to the analysis and interpretation of the results, additionally that it enables to reduce costs, by the participation of staff directly involved in these activities. The program also helps to reduce and prevent human errors [15] due to data processing.

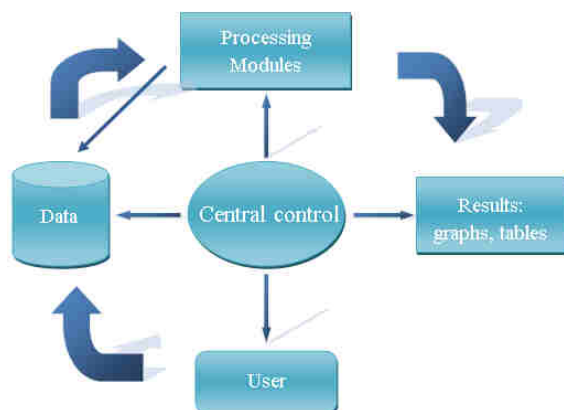


Fig.1: Representative diagram of the architecture used by ANAGEOT and user interaction with different modules.

2.2 Items required for proper operation

This application requires for proper operation, data previously reviewed and classified by theme, which are incorporated into the database of the field to which they relate. Each database is identified by the name of the geothermal field, and there are databases, according to incorporated geothermal fields. This information is stored in a relational database model, consisting of a set of tables and views. Views are virtual tables whose contents are defined by the query of one or more real tables, which in turn can also be treated as a real table.

The tables in the database are comprised of the following groups of data:

- Production Data: Enthalpies, pressures, flow rate of liquid, steam and mixture.
- Isotopic data (oxygen-18 and deuterium)
- Chemical data: Liquid phase and gaseous phase.
- Daily injection data

2.3 ANAGEOT modules

Upon entering the application, a welcome screen that provides a brief description of their functionality (Figure 2) it is shown. Subsequently enters a window displaying geothermal fields, whereby it is possible to select from a list of elements, the field in which user wants to work.

The main menu consists of several modules, which have generally the functionality to perform these calculations:

- Chemical composition of total discharges
- Production of steam and liquid
- Changes in production of liquid and steam mixture (Using normalized and Linear settings)
- Interpolation settings
- Geothermometers
- Interpolation enthalpy of steam tables
- Enthalpy comparisons estimated by different methods over time (total discharge enthalpy and

enthalpy of SiO_2 and Cationic Composition Geothermometer (CCG) enthalpy)

- Injection rate
- Changes in the chemical composition of the liquid
- Gas balance methods

These calculations are generated for a well or to a group of wells and can be represented graphically. Graphing package that is used is Golden Grapher V. 8 which was applied to the case studies described here. Another way of presenting the results is by generating reports text documents and spreadsheets (Microsoft Word and Excel) respectively. The software can be considered for widespread use; additionally the recent files generated can be taken as source documents for other applications.

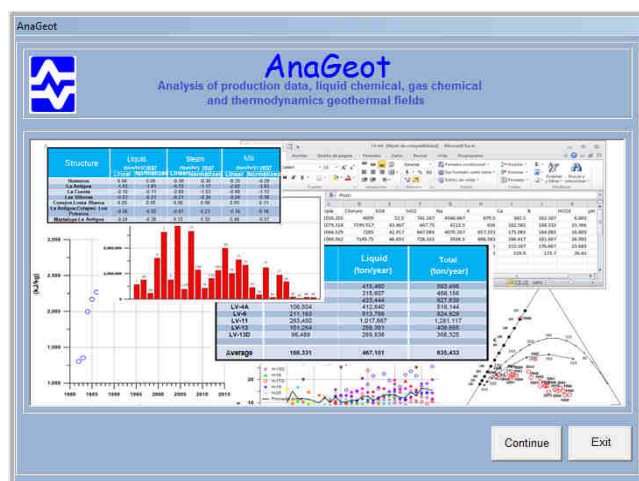


Fig. 2: Welcome screen of ANAGEOT.

This menu has a catalog of wells, chemical liquid data and chemical gaseous data where it is possible to introduce, edit or delete information from the producing and/or injector wells. It also contains a selection window of geothermal field so that it can change to different fields at any time.

Graphic section consists of two modules, for a comprehensive and individual analysis. In these modules, for generating graphs, automatically it opens the application to Golden Grapher. With this software it can edit or perform any of the actions that the program allows on the generated graph.

It consists of an assistant that allows the user to perform a series of graphs and analysis of a well. It can be edited the visual characteristics of both symbols and lines (see Figure 3). Example of a graph generated with ANAGEOT of Ar-N2/100-10He ratio for a well is shown in Figure 4.

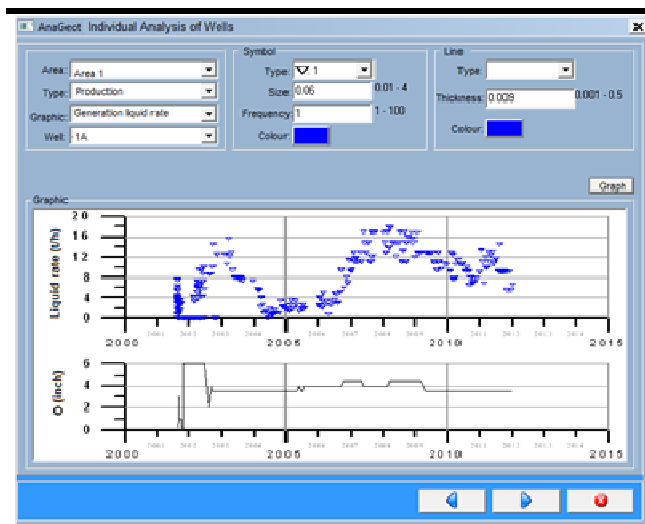


Fig. 3: Graph generation liquid rate vs time for well 1A.

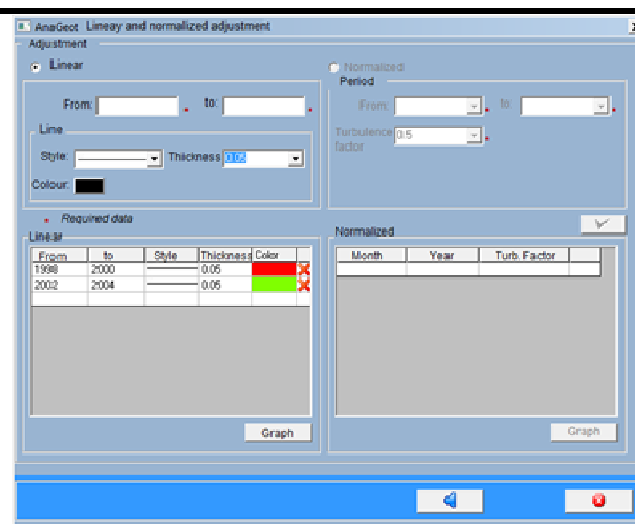


Fig. 5: Window linear and normalized fit.

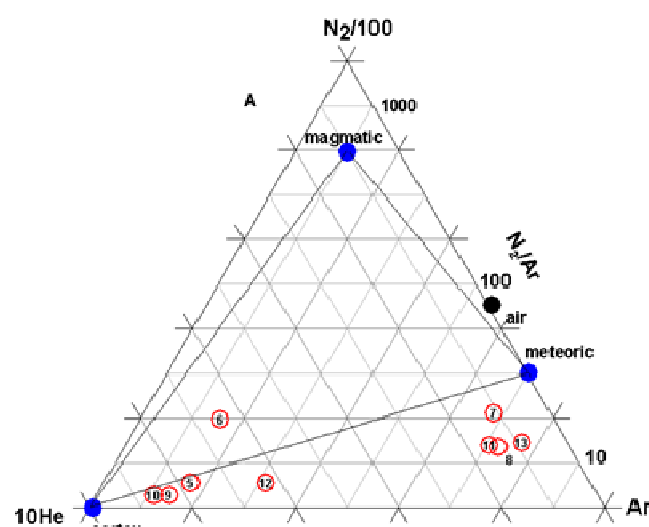


Fig. 4: Chart generated with ANAGEOT of Ar-N2 / 100-10He ratio to the well A.

Using the program it can perform linear and normalized graphics settings, allowing to see, trends and rates of change in the production of the well analyzed. An example is shown in Figure 5, where the well performance is studied along time of operation. The representation of the results is done automatically in Grapher with a description of each linear fit (Figure 6) and a graphical representation of the calculated data with normalized fit as shown in Figure 7.

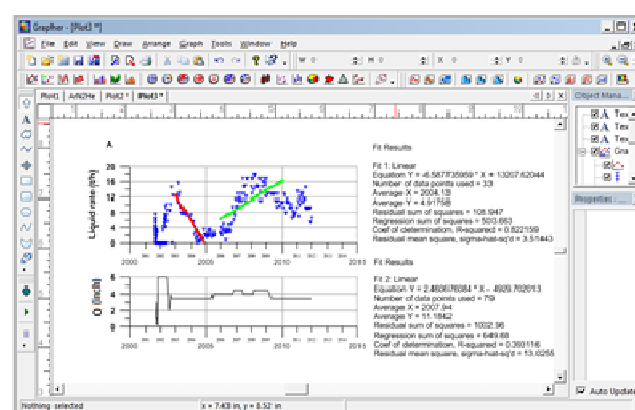


Fig. 6: Graphical representation of linear fit program using the Grapher software.

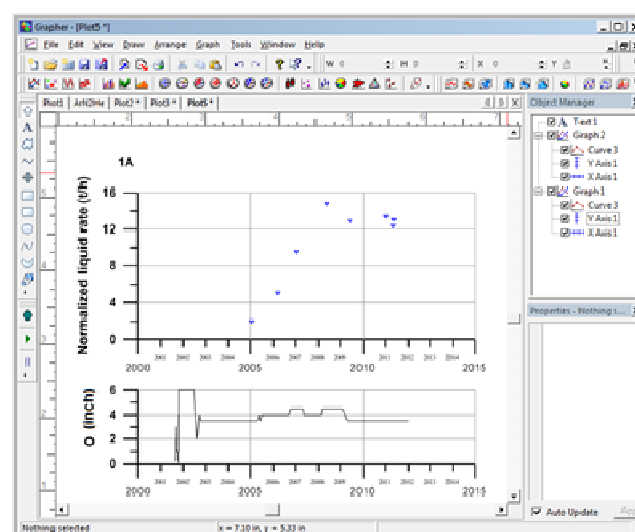


Fig.7: Graphical representation of normalized fit, calculated using the Grapher software.

Inside this module it is also possible to compare the enthalpy of the well, estimated by different methods, with the enthalpy of the total discharge, to identify reservoir

processes [1]. It can be carried out two type of analyzes; one that involves dividing historical data into three periods (three cases) and other one with all historical data (general case). An example of enthalpy analysis is shown, in Figure 8, for three time intervals using data of the well 5.

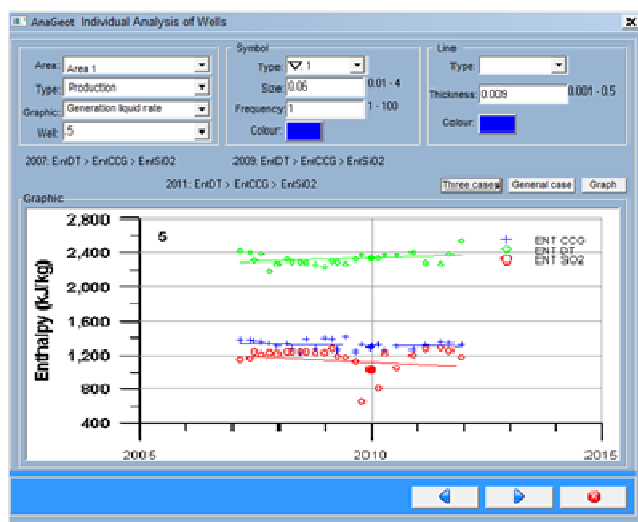


Fig. 8: Behavioral analysis enthalpy for three conditions vs time in the well 5.

The global analysis module allows construct graphics using data from a group of wells for a given period. The Mexican geothermal fields classify their wells by area, ANAGEOT handles the same classification for the graphical representation global. Figure 9 shows the graph of chlorides in water wells separated in one area of the field.

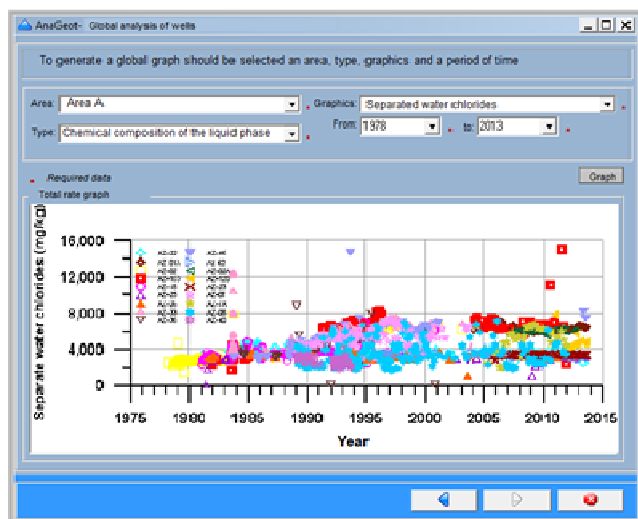


Fig. 9: Graphical representation of chlorides in the water separated for a group of wells.

Reports menu contains five modules, which generate documents in Word and/or Excel, it can be edited or perform actions allowed by the applications. With these modules can perform a series of calculations of a well or

group of wells in a given period of time. Modules in this section are:

Through this module it can be done various reports related to production. The information is validated to confirm that it has the minimum required for reliable results. In case of not having the required information, a summary is displayed with the details of the validation. Examples of some reports that can be generated in this module are presented. In Figure 10 the fluid Report window with the "Report Years Effective" production for a group of wells is shown. Figure 11 shows an example of reporting total production for a group of wells that fluid report module generates in a Word document.

Allows make reports of change velocity of several parameters of a well, using linear and normalized fit [16]. In Figure 12 the window Reporting declines is displayed with changes obtained for production of liquid, steam and mixed with both types of analysis (linear and normalized fit).

Allows make reports of injection wells, using information from daily injection. In Figures 13 and 14 the report injection window is shown with the annual average for a group of injection wells and their respective document generated in Excel.

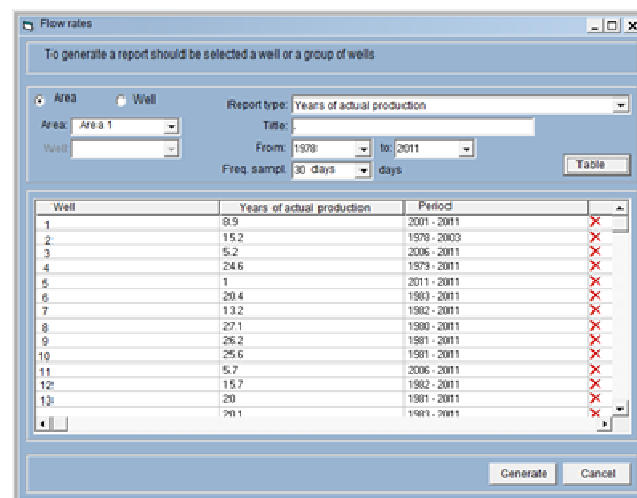
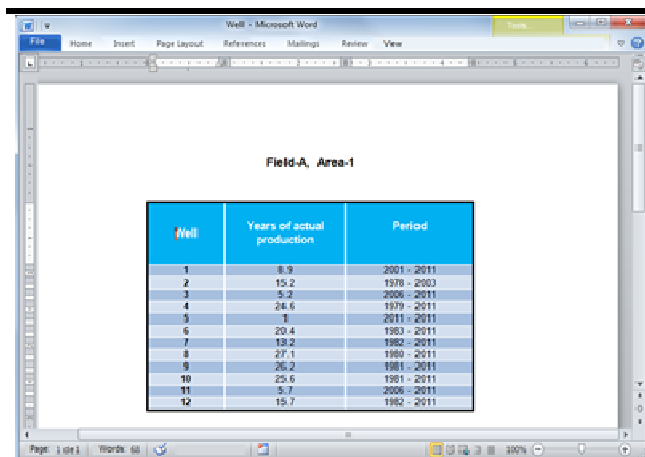
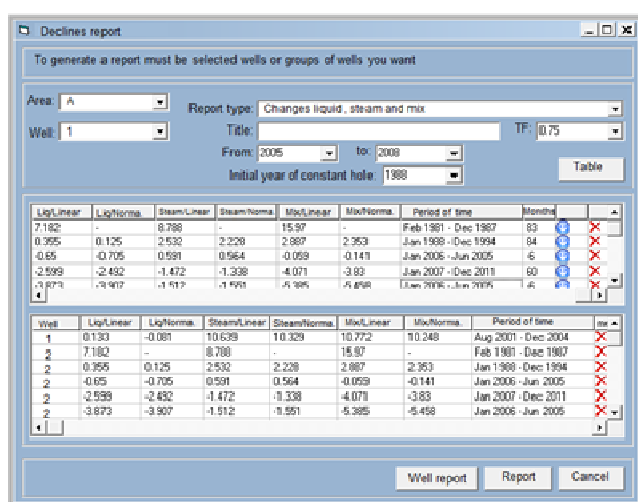


Fig.10: Window fluid report and table with years of actual production of a group of wells.



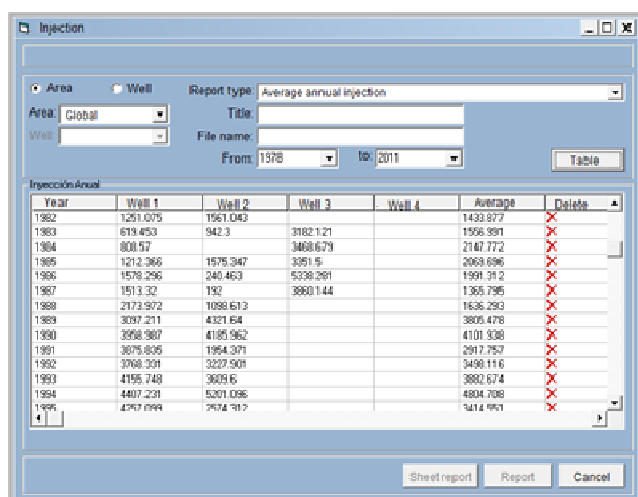
Well	Years of actual production	Period
1	8.9	2001 - 2011
2	15.2	1978 - 2003
3	5.2	2006 - 2011
4	24.6	1979 - 2011
5	1	2011 - 2011
6	20.4	1963 - 2011
7	13.2	1982 - 2011
8	27.1	1960 - 2011
9	26.2	1981 - 2011
10	25.6	1981 - 2011
11	5.7	2006 - 2011
12	19.7	1982 - 2011

Fig. 11: Example reporting total production of a group of wells.



Well	Liq/Linear	Liq/Norma	Steam/Linear	Steam/Norma	Mix/Linear	Mix/Norma	Period of time	Months
1	7.182	-	8.788	-	15.97	-	Feb 1981 - Dec 1987	83
2	0.955	0.125	2.532	2.228	2.887	2.353	Jan 1988 - Dec 1994	84
3	0.65	0.705	0.591	0.564	-0.059	-0.149	Jan 2006 - Jun 2005	6
4	-2.599	-2.452	-1.472	-1.338	-4.071	-3.69	Jan 2007 - Dec 2011	60
5	-3.877	-3.917	-1.517	-1.551	-5.385	-5.458	Jan 2006 - Jun 2005	6

Fig. 12: Display reporting of decline rates of liquid, steam and mixture production.



Year	Well 1	Well 2	Well 3	Well 4	Average	Delete
1982	1251.075	1561.043	-	-	1433.877	X
1983	619.453	942.3	3182.121	-	1556.891	X
1984	808.57	-	3468.679	-	2167.772	X
1985	1212.365	1575.347	3351.5	-	2063.696	X
1986	1578.295	240.453	5338.261	-	1991.312	X
1987	1513.32	192	3880.144	-	1365.795	X
1988	2173.972	1099.613	-	-	1636.293	X
1989	3097.211	4321.64	-	-	3805.478	X
1990	3958.987	4185.962	-	-	4101.938	X
1991	3875.835	1954.371	-	-	2917.757	X
1992	3768.331	3227.901	-	-	3498.116	X
1993	4155.748	3609.6	-	-	3882.674	X
1994	4407.231	5201.096	-	-	4804.708	X
1995	4257.099	2574.312	-	-	3414.551	X
1996	3907.858	2198.4	-	-	3059.023	X
1997	2275.332	2696.548	-	-	2485.94	X
1998	1180.315	1833.415	-	-	1518.277	X
1999	1570.784	1300.997	-	-	1435.89	X
2000	2625.18	2243.803	-	-	2434.492	X
2001	1631.233	2195.441	-	-	1934.973	X
2002	1299.537	2315.441	-	-	1870.006	X
2003	1255.617	3562.389	-	-	2460.155	X
2004	-	3230.098	-	-	3230.098	X
2005	-	1935.692	-	2549.955	2103.665	X
2006	-	2686.215	-	2431.627	2558.571	X
2007	-	2961.995	-	2785.912	2874.074	X

Fig. 13: Example of an average annual report of injected fluid for a group of wells.

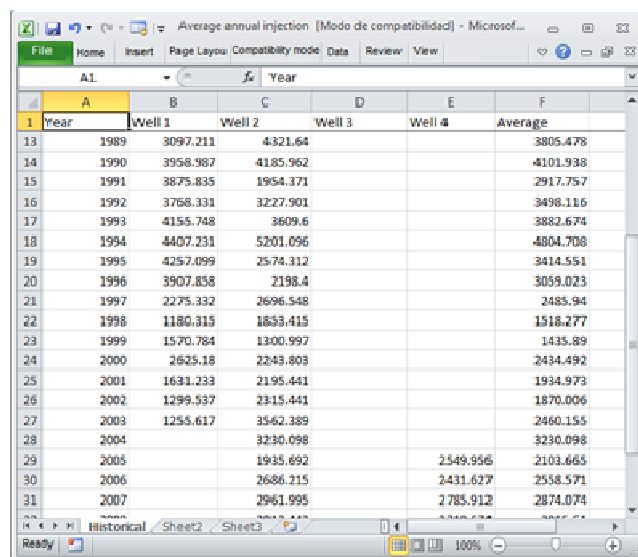
These modules allow reports for wells in a period of time, maintaining the same characteristics of window design

than those shown in Figure 13. Reports generated in Excel for chemical composition of liquid phase and steam, are similar to that shown in Figure 14.

ANAGEOT has an online help tool, which allows to access in at any time when the application is active.

III. CONCLUSION

ANAGEOT is a tool developed specifically to aid in the study of geothermal reservoirs, aiding in the interpretation of the behavior of wells according to their thermodynamic, chemical and production conditions; however it is important to consider that success largely to be taken in the use of this application is determined by the quality of the information entered in the ANAGEOT database. So far the tool has been successfully used in projects, applied in Mexican geothermal fields, optimizing the time consumption in processing information. It has also opened the possibility of further use in future projects.



Year	Well 1	Well 2	Well 3	Well 4	Average
1989	3097.211	4321.64	-	-	3805.478
1990	3958.987	4185.962	-	-	4101.938
1991	3875.835	1954.371	-	-	2917.757
1992	3768.331	3227.901	-	-	3498.116
1993	4155.748	3609.6	-	-	3882.674
1994	4407.231	5201.096	-	-	4804.708
1995	4257.099	2574.312	-	-	3414.551
1996	3907.858	2198.4	-	-	3059.023
1997	2275.332	2696.548	-	-	2485.94
1998	1180.315	1833.415	-	-	1518.277
1999	1570.784	1300.997	-	-	1435.89
2000	2625.18	2243.803	-	-	2434.492
2001	1631.233	2195.441	-	-	1934.973
2002	1299.537	2315.441	-	-	1870.006
2003	1255.617	3562.389	-	-	2460.155
2004	-	3230.098	-	-	3230.098
2005	-	1935.692	-	2549.955	2103.665
2006	-	2686.215	-	2431.627	2558.571
2007	-	2961.995	-	2785.912	2874.074

Fig. 14: Excel report of average annual injection of a group of wells.

IV. ACKNOWLEDGEMENTS

The program was developed under project IIE-14432: "Mejoras e implementación de nuevas funcionalidades al sistema auxiliar en el análisis e interpretación de datos químicos isotópicos y de producción de pozos y campos geotérmicos", with support of Geothermal Department, of Electrical Research Institute of México.

I greatly appreciate the IIE and M. I. Victor Arellano Gómez[†] for their invaluable support during the development of the project; and the participation of the coauthors, especially Dr. Alfonso Aragon for his advice and encouragement.

REFERENCES

- [1] A. H. Truesdell, "Effects of physical processes on geothermal fluids", In Application of geochemistry in geothermal reservoir development, F. D'Amore, ed. UNITAR/UNDP Centre on small energy resources, Rome, 1991, pp. 71-92.
- [2] S. Arnórsson, and F. D'Amore, "Monitoring of reservoir response to production. In: (Arnórsson S., ed.) Isotopic and chemical techniques in geothermal exploration, development and use, International Atomic Energy Agency", Vienna, 2000, pp. 309-351.
- [3] V. M. Arellano, M. A. Torres, R. M. Barragán, F. Sandoval and F. Lozada, "Chemical, Isotopic and Production Well Data Analysis for the Los Azufres (Mexico) Geothermal Field", Geothermal Resources Council Transactions, vol. 27, pp. 275-279, 2003.
- [4] V. M. Arellano, M. A. Torres, and R. M. Barragán, "Thermodynamic Evolution of the Los Azufres, Mexico, Geothermal Reservoir from 1982 to 2002". Geothermics, vol. 34, pp. 592-616, 2005.
- [5] V. M. Arellano, R. M. Barragán, A. Aragón, M. H. Rodríguez, and A. Pérez, "The Cerro Prieto IV (Mexico) geothermal reservoir: Pre-exploitation thermodynamic conditions and main processes related to exploitation (2000-2005)". Geothermics, 40 (3), pp. 190-198, 2011.
- [6] V. M. Arellano, R. M. Barragán, S. López, A. Paredes, and A. Aragón, "Respuesta del Yacimiento de Los Azufres a la Explotación 2003-2011". Informe, IIE/11/14283/02F, Instituto de Investigaciones Eléctricas para la Comisión Federal de Electricidad, Cuernavaca, Morelos, México, 2012, 303 p.
- [7] R. M. Barragán, V. M. Arellano, E. Portugal, and F. Sandoval, "Isotopic ($\delta^{18}\text{O}$, δD) patterns in Los Azufres (Mexico) geothermal fluids related to reservoir exploitation". Geothermics, 34, pp. 527-547, 2005.
- [8] R. M. Barragán, V. M. Arellano, I. Martínez, A. Aragón, L. Reyes, and R. González, "Patrones de comportamiento de especies químicas e isotópicas (2006-2007) en el campo geotérmico de Los Azufres, Mich., en respuesta a la reinyección". Geotermia, 22 (2), pp. 19-27, 2009..
- [9] A. H. Truesdell, M. J. Lippmann, J. L. Quijano, and F. D'Amore, "Chemical and physical indicators of reservoir processes in exploited high-temperature, liquid-dominated geothermal fields". Proc. World Geothermal Congress, Florence Italy, 1995, pp. 1933-1938.
- [10] V.M. Arellano, R. M. Barragán, S. López, A. Paredes, and A. Aragón, "Respuesta del Yacimiento de Los Humeros a la Explotación 2007-2012". Informe, IIE/11/14531/02F, Instituto de Investigaciones Eléctricas para la Comisión Federal de Electricidad, Cuernavaca, Morelos, México, 2013a, 229 p.
- [11] V. M. Arellano, R. M. Barragán, S. López, A. Paredes, and A. Aragón, "Respuesta del yacimiento de Las Tres Vírgenes a la explotación 2007-2012". Informe final IIE/11/14530/I 01/F para la Comisión Federal de Electricidad, México, 2013b, 78 p.
- [12] J. W. Lund, and H. F. Derek, "World-wide direct uses of geothermal energy 2000", Geothermics, 30 (1), pp. 29-68, 2001.
- [13] B. Matek, "2016 Annual U. S. & Global Geothermal Power Production Report, Geothermal Energy Association", Washington D.C. U.S.A., 2016. 36 p.
- [14] Y. He , G. Wang, W. Lin, and W. Zhang, "The Analysis of Heat Storage Capacity and the Formation Characteristics of Geothermal Resources in Sedimentary Basins — A Case Study on Dunhuang Basin", The Open Fuels & Energy Science Journal, 8, pp. 73-76, 2015.
- [15] S. Mohan, and N. Ramsundram, "Predictive Temporal Data-Mining Approach for Evolving Knowledge Based Reservoir Operation Rules", Water Resources Management, 30, pp. 1-16, 2016.
- [16] S. K. Sanyal, A. J. Menzies, P. J. Brown, K. L. Eneedy, and S. Eneedy, "A systematic approach to decline curve analysis for the Geysers steam field, California", Geothermal Resources Council, Transactions, 13, pp. 415-421, 1989.