Analele Universității din București. Informatică
Vol. LXIII, p. 83-91
ISSN 3045-2392; e-ISSN 3045-2406

Denis ENĂCHESCU[1]

SIMULATION OF HYDRO-THEORMO-MINERAL AQUIFERS

Abstract. The paper aims to synthesize the thermo-mineral aquifer simulation methodology elaborated, in the 80s, at the Computing Center of the University of Bucharest, C.C.U.B. Professor Ion Văduva initiate a research contract between C.C.U.B. and the Geological Reserve Coordination Department of the Ministry of Geology, G.R.C.D. The result of this joint contract, carried out over several years, is the methodology presented in this paper. Based on this methodology, a software was written and successfully applied to optimize the exploitation of aquifers in the Oradea area.

Keywords: numerical simulation, parabolic partial differential equations, Galerkin method, thermo-mineral underground aquifers

If people do not believe that mathematics is simple, it is only because they do not realize how complicated life is.
(JOHN von NEUMANN)

1. Introduction

From a hydrogeological point of view, optimizing the exploitation of a hydro-thermo-mineral system consists in optimizing the distribution of the wells and the exploitation regime so that both the global flow rate,

[1] Prof. Emeritus, University of Bucharest, Faculty of Mathematics and Computer Science, and Associate Chief Editor at *Analele UB. Informatică*. E-mail: <denaches@fmi.unibuc.ro>.

EDITURA UNIVERSITĂȚII DIN BUCUREȘTI
BUCHAREST UNIVERSITY PRESS

the concentration and the temperature of the thermal-mineral waters exploited, as well as the conditions imposed for the conservation and protection of the reservoir be satisfied.

To achieve this goal, it is necessary to simulate (Văduva, 1976) the behavior of the system in different variants of exploitation of the thermo-mineral waters field, simulation based on the location of the optimal capture in terms of the above-mentioned conditions.

The mathematical model used in the simulation and prognosis of the evolution of a hydro-thermo-mineral underground system that evolves in a non-stationary regime is given by the general process equation

$$\frac{\partial \psi}{\partial t} = \boldsymbol{a}\ \mathbf{div}\ \mathrm{grad}(\psi) - \vec{v}\ \mathbf{grad}(\psi) + \boldsymbol{c} \tag{1}$$

with mixed conditions on the boundaries.

The fundamental idea of the simulation and prognosis of a system described by (1) is that the characteristic parameters and its hydrodynamics can be appreciated on the basis of hydro-, thermal-, mineralization-equipotential-lines maps at two consecutive times, separated by appropriate ranges of hundreds or thousands of days.

2. The model

This theoretical foundation of hydrogeological data processing and interpretation has been approved by G.R.C.D. Starting from this idea, using the laws of mass preservation, temperature and concentration, as well as those of Darcy's linear filtration, Fick's diffusion and Fourier thermoconductance, the system (1) is obtained

$$\begin{aligned}
\frac{\partial \psi_1}{\partial t} &= \boldsymbol{a}_1 \mathbf{div}\ \mathrm{grad}(\psi_1) + \boldsymbol{c}_1 \\
\frac{\partial \psi_2}{\partial t} &= \boldsymbol{a}_2 \mathbf{div}\ \mathrm{grad}(\psi_2) - \frac{\rho c}{\widetilde{\rho c}} \overrightarrow{v_2}\, \mathbf{grad}(\psi_2) + c_2 \\
\frac{\partial \psi_3}{\partial t} &= \boldsymbol{a}_3 \mathbf{div}\ \mathrm{grad}(\psi_3) - \frac{\overrightarrow{v_3}}{m_2} \mathbf{grad}(\psi_3) + c_3
\end{aligned} \tag{2}$$

describing the propagation by infiltration of the hydrodynamic active particles, the propagation of the heat through convection and conduction and the propagation of the concentration of the mineral components by hydrodynamic dispersion (convection and molecular diffusion) in the active hydrodynamic fluid mixture (Albu and Enăchescu, 1981; Enăchescu, 1981; Enăchescu and Albu, 1982).

In the system (2):

- a_1, a_2, a_3 are the coefficients of hydraulic diffusivity (piezo-transmissivity), respectively thermal diffusivity by the aggregate of the rock and stored water and the dispersion diffusivity coefficient (hydrodynamic dispersion);
- ρ, c represents the specific mass and specific heat (calorific capacity) of the active hydrodynamic water;
- $\tilde{\rho}$ and $\tilde{c}$ represents the specific mass and specific heat of the rock of effective porosity m_2 and the stored water;
- $\vec{v} = -k\,\mathrm{grad}(\psi_1)$ is the filtration velocity, according to Darcy's law, through the product of hydraulic conductivity *k* and the changed sign gradient of the piezometric load;
- c_1, c_2, c_3 are the specific additional vertical productivity per unit capacity of water, heat and mineralization, respectively.

As can be easily observed, the system equations (2) are cases of the general process equation (1).

Particularly interesting results have been obtained in solving system (2) with mixed conditions through multistep Galerkin method, using the Courant triangle as finite element and a time-step τ (Enăchescu and Olariu, 1983).

3. The OPT-APE-HTC software

Since early 80s, at the C.C.U.B. a software package was developed, tested and implemented, which, starting from measurements made in the existing drillings, estimates the parameters and forecasts the evolution of a real hydro-thermo-mineral system in different exploitation variants.

The OPT-APE-HTC software was the first program package in Romania, and the international one among the few, which completely model with a minimum of data, effort and expense the most complex and general type of hydro-thermo-mineral system.

Issues, objectives, performance, limits, domain of applicability

The OPT-APE-HTC software addresses the issue of automatic evaluation of the exploitable reserves of underground thermal water, namely the evaluation of the characteristic parameters of the hydro-thermo-mineral system and its evolution to optimize the system and the exploitation regime.

Because the optimization of the system and its operating regime require the simulation of the aquifer behavior in different variants of the wells locations, the OPT-APE-HTC software package is also provided with a simulation module of other exploitation variants than the current one.

The limits of the applicability domain for the OPT-APE-HTC software are given by the existence and uniqueness assumptions of the mixed problem solution for parabolic equations.

Structure of the OPT-APE-HTC software package

Without going into detail, the OPT-APE-HTC program package is made up of the following main modules:

- **M1)** the HIDROBAZ module, to create, maintain and manage all information about the underground modeled systems;
- **M2)** the CALARMOD module, to fit the model so that it corresponds to the real case of the investigated hydro-thermal-mineral system;
- **M3)** the ESTPARAM module, to estimate the parameters of the investigated hydro-thermo-mineral system;
- **M4)** the PROGEVOLACT module, to forecast the evolution of the investigated hydro-thermo-mineral system, in the current exploitation variant;
- **M5)** the PEOGEVOLDIF module, to simulate the evolution of the system in other exploitation variants than the current one.

Output of the OPT-APE-HTC software

The main output lists are, approximately in the order of their obtaining in a full running of the software, the following:

L1) tables with the values of the aquifer parameters estimated in optimal partition areas according to the least squares method. Upon request, condition equations and normal equation systems can also be listed;

L2) the tables with the values of the three fields, at different time points, in all the nodes of the network, respectively the optimal triangulation, obtained by numerical integration of the system (2). On request we can automatically draw the maps with the actual and predicted iso-lines.

OPT-APE-HTC software inputs

The inputs of the software are made up of the basic materials delivered by the drilling contractor, studies of the evolution of the hydrogeological characteristics of the drilling, etc. The way of collecting and selecting the data from drillings in exploitation and from the observation drills of a hydro-thermo-mineral system is the subject of a unique methodology elaborated by the *Geological Reserve Coordination Department of the Ministry of Geology*.

Regarding the size order of the meshing steps, it is recommended that they be in the order of hundreds or thousands of meters for space and thousands of days for time, so that the applicability of diffusivity equations is warranted.

4. Applications

The above-described software was applied to simulate two hydro-thermo-mineral systems which evolve in the thermodynamic conditions of the geothermal anomaly of the Pannonian depression, where the geothermal gradient has an average value of about 20 m/°C, namely:

- the Cretaceous fissured limestone system from Băile Felix – 1 Mai where the underground flow results from the mixture of the local inflow of thermal waters with the regional inflow of cold waters;
- the intergranular system of Pontian sands from Biharia Săcuieni under hydrodynamic conditions of storage under pressure in a typical hydro-structure of Pannonian Depression.

The zonal parameters of the system are determined (Table 1) by solving the normal equations corresponding to the vertices of each square of the network, based on the hydro-thermo-mineral isolines maps at two moments, separated by a time interval of $\tau = 10{,}000$ days for the Cretacic

Table 1

Parameters of the hydro-thermo-mineral systems

Hydro-thermo-mineral system			Băile Felix – 1 Mai Cretaceous limestone	Biharia – Săcuieni Pontian sandstone
Discretization steps		τ day	10,000	2,500
		λ m	500	1,000
a_1, coefficient of rheo-mechanical transmissivity	Nr. of measurements		4	126
	$\frac{m^2}{day}$	mean	40.88	816.41
		minimum	21.93	3.57
		maximum	66.01	9608.85
c_1, rheo-mechanical productivity per unit capacity	Nr. of measurements		3	126
	$\frac{m}{day}$	mean	-0.000171	-0.012393
		minimum	-0.000056	-0.006699
		maximum	-0.000261	-0.020107
a_2, coefficient of thermal transmissivity	Nr. of measurements		4	26
	$\frac{m^2}{day}$	mean	4.62	159.29
		minimum	2.10	2.71
		maximum	5.71	549.12
$\vec{v}_3$, diffusion / dispersion convective velocity	Nr. of measurements		4	26
	$\frac{m}{day}$	mean	8.05	816.41
		minimum	1.23	3.57
		maximum	11.46	9608.85
c_3, diffusive / dispersive productivity per unit capacity	Nr. of measurements		1	26
	$Kg{*}m^{-3}{*}s^{-1}$	mean	-0.000066	0.000342
		minimum		-0.000032
		maximum		0.000497

a_3, diffusive / dispersive coefficient of transmissivity	Nr. of measurements		4	33
	$\frac{m^2}{day}$	mean	0.25	337.80
		minimum	0.09	27.32
		maximum	0.32	1715.34
$\vec{v}_2$, thermal convective velocity	Nr. of measurements		4	33
	$\frac{m}{day}$	mean	1.24	680.51
		minimum	0.58	1.14
		maximum	1.83	8054.57
c_2, thermal productivity per unit capacity	Nr. of measurements		3	32
	$^{\circ}C\,\frac{\square}{day}$	mean	-0.000198	-0.003523
		minimum	-0.000173	-0.006489
		maximum	-0.000232	-0.009897

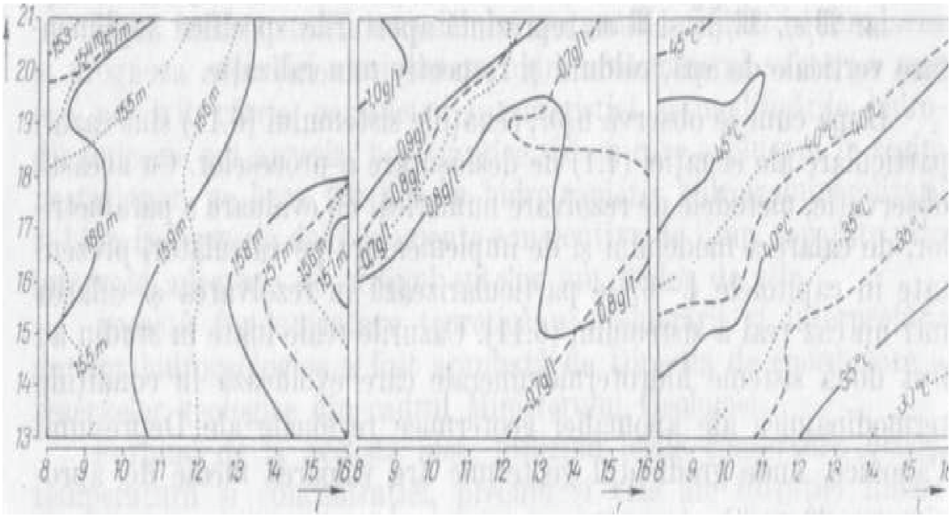

Figure 1. The evolution of the hydro-thermo-mineral system from the Cretaceous limestone of Băile Felix – 1 Mai in a representative sub-area, where the hydro, thermo and mineralization isolines are traced through continuous lines at the initial moment t_0 through interrupted lines at the actual moment t_1=t_0+10,000 days and through dashed lines at the next moment t_2=t_0+20,000 days

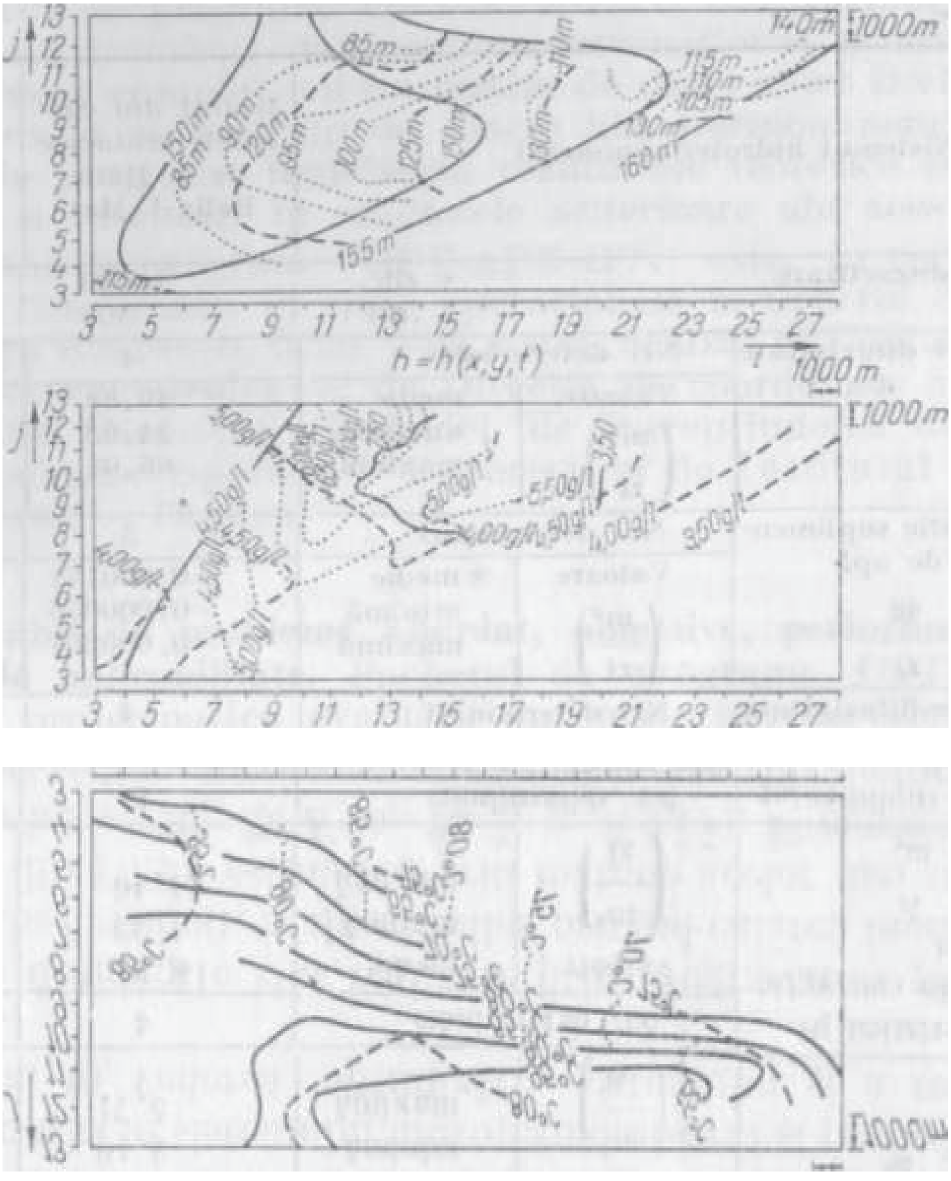

Figure 2. The evolution of the hydro-thermo-mineral system in the Pontian sands of Biharia-Săcuieni, in a representative sub-area, where thermo and mineralization isolines are traced through continuous lines at the initial moment t_0 through interrupted lines at the actual moment $t_1=t_0+2{,}500$ days and through dashed lines at the next moment $t_2=t_0+5{,}000$ days

system and $\tau = 2{,}500$ days for the Pannonian system and using the explicit bi-dimensional differences schemes on a squared grid with $\lambda = 500$ m for the fissured system and $\lambda = 1{,}000$ m for the intergranular system (Albu et al., 1980).

The simulation results are presented in Fig. 1 and Fig. 2.

This simulation revealed a pulsating evolution of the aquifer, due to the drilling holes, as well as the role of stationary lines played by the geological faults within the system.

Bibliography

Albu, M., Paâl, G., Enăchescu, D.M. (1980). *Stabilirea condițiilor de alimentare a zăcămintelor geotermale din județul Bihor.* [Determination of the intake conditions of the geothermal aquifers in Bihor County] Preprint Institutul de Învățământ Superior Oradea, Oradea.

Albu, Marius, and Enăchescu, D.M. (1981). "Despre simularea evoluției sistemelor hidrotermominerate subterane." [About simulating the evolution of underwater hydrothermal systems] *Studii și Cercetări de Geol., Geof., Geogr.*, seria Geofizică 19, p. 143-155.

Enăchescu, Denis. M. (1981). *Metodologie unitară de colectare, sistematizare, şi prelucrare a datelor in vederea estimării parametrilor şi prevederii evoluției unui sistem hidro- termomineral subteran in varianta actuală de exploatare.* [Uniform methodology for collecting, systematizing, and processing data in order to estimate the parameters and forecasting the evolution of a geothermal system in the current exploitation variant.] Preprint C.C.U.B., Bucureşti.

Enăchescu, Denis M., and Albu, M. (1982). "Integrarea numerică a ecuațiilor de difuzivitate orizontală pentru zăcămintele hidrotermominerale." [Numerical integration of horizontal diffusivity equations for hydro-thermo-mineral aquifers] *Studii şi Cercetări Mat.*, 34, 2, p. 112-124.

Enăchescu, Denis M., and Olariu, S. (1983). *Simularea acviferelor sub presiune neomogene, cu frontiere oarecare.* [Simulation of non-homogeneous aquifers under pressure, with any type of boundaries] Preprint C.C.U.B., Bucureşti.

Văduva, Ion (1977), *Modele de cu calculatorul*, Editura Tehnica.

All links were verified by the editors and found to be functioning before the publication of this text in 2024.

DECLARATION OF CONFLICTING INTERESTS
The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING
The author received no financial support for the research, authorship, and/or publication of this article.