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Teaching and learning of fundamental concepts of ground water flow by a specific educational software

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Abstract

The educational software FATSIM-A has been developed to simulate transient, non-lineal, conjugate problems of fluid flow and solute transport in porous media. Characteristics of the commercial codes, such as communications with the user in a pleasant windows environment, selection of the mesh grid, capabilities of advanced programming, etc. are installed in the software. The resulting simulation data (concentration and stream function isolines), including animations, are graphically shown in the environment of FATSIM-A itself or using MATLAB, due to suitable routines implemented in the software. The program can be used as a low cost laboratory educational tool for teaching groundwater flow with solute transport processes, such as saline intrusion, salt lake and salt dome problems. The program allows the user the information of the text file Spice code, whose structure and design rules can be easily accessed by graduate and under-graduate students with a basic knowledge of electrical circuit theory. Models designed by FATSIM-A of several sceneries implemented by students were explained to check the understanding of the problem.

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Keywords: educational software; teaching in engineering; design mathematical models; Spice code

1. Introduction

When the possibility of teaching in a course of Engineering Master arises, the main question that appears is what would be the best tool so that students could understand the standard well-known benchmark problems.

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Given the extensive experience of the research group components in numerical simulation using the network method and Spice code, the idea of developing a software with a friendly environment to allow students the understanding of this difficult problem arose.

Nomenclature

c	concentration (kg m^{-3})
D	dispersion coefficient as used by Henry (m^2 s^{-1})
g	gravitational acceleration (m s^{-2})
k	aquifer permeability (m^2)
q	specific discharge (m s^{-1})
t	time (s)
ν	groundwater velocity (m s^{-1})
x, z	spatial coordinates (m)
β	coefficient of solute volume expansion
ε	porosity (dimensionless)
ψ	stream function (m^2 s^{-1})
μ	dynamic viscosity of saltwater (kg m^{-1} s^{-1})
ρ	density (kg m^{-3})

The network method is firstly based on the electrical analogy and extends in many engineering text books as an educational tool for better understanding the theoretical content of the mathematical models of physical and engineering kinds of processes. This, as well as any class of analogy between physical problems is ‘‘per se’’ an undoubted educational subject since the mathematical models of many problems rests in the same differential or partial differential equations [Mills (1999) and Chapman (1960)].

In this work is gone beyond the merely academic and is presented a new software capable of simulating 2-D, fluid flow, and solute transport processes in porous media: FATSIM-A [Alhama *et al.* (2010) and Alhama *et al.* (2011a)]. The software was developed by the research group ‘‘Simulation by network’’ of the Universidad Politécnica de Cartagena.

FATSIM-A is designed to be applied in several fields: (i) academic, as an educational tool regarding connection between two physical processes which are equivalent from the point of view of their mathematical formulation, (ii) didactic and economic, as regards the possibility of carrying out low-cost laboratory practices of the groundwater flow discipline, and (iii) investigation and design, as regards the kind of problems which can be treated with the software [Alhama *et al.* (2010) and Alhama *et al.* (2011a)].

Finally, FATSIM-A has been designed to make use of the advance and powerful programming capabilities of Spice code since these are presented to the user in suitable windows. For example, it is possible to simultaneously run models of the same problem for which a parameter has a discrete range of values, or to compare the same variable of two models. Another fundamental advantage is, of course, that the user does not need to manage the mathematical equations involved (from the point of view of their organization for the numerical calculus) since this work is done by Spice software. FATSIM-A has been made as an open program to help users as much as possible since they can access directly the models at any step and modify them to their convenience, changing, for example, the hydrological or geometrical parameters of a particular region as well as other data of the model, the boundary conditions, the time window of the simulation, etc. [Alhama *et al.* (2011b)].

2. The governing equations

The 2-D general scenario of these problems is governed by the continuity [Cerro *et al.* (2008) and Alhama *et al.* (2011b)], flow and solute transport and the constitutive Darcy equations. These are

$$\nabla(\rho q) = 0 \tag{1}$$

$$\frac{\partial c}{\partial t} - \nabla(cv) = \nabla(D \nabla \rho) \tag{2}$$

$$\left(\frac{\mu}{k}\right) q + \nabla p - (\Delta \rho) g = 0 \tag{3}$$

with q =νε. Besides, the concentration dependence of the saltwater density is assumed as $\Delta\rho=\rho_f \beta(\Delta c)$. Moreover, can be assumed the Boussinesq approximation hypothesis, $\rho \approx \rho_f$. Now, if is introduced the definition of the stream function

$$\frac{\partial \psi}{\partial x} = q_z, \frac{\partial \psi}{\partial z} = -q_x \tag{4}$$

and making use of the Darcy equation, the flow continuity equation is written as

$$\frac{\partial\left(k_z^{-1} \frac{\partial \psi}{\partial x}\right)}{\partial x} + \frac{\partial\left(k_x^{-1} \frac{\partial \psi}{\partial z}\right)}{\partial z} = -\frac{g \rho_0 \beta}{\mu} \frac{\partial c}{\partial x} \tag{5}$$

If is assumed anisotropy, the governing Equations (2) and (5) are the basis for the design of FATSIM-A.

3. FATSIM-A

Figure 1 shows a simplified scheme of the flow diagram of FATSIM-A. Two main characteristics of the program for the simulation of unsteady flow and solute transport processes are easy handling by the user and an ability to carry out powerful calculations. This demands the use of a visual source code to provide creative, editing, and handling capacities with online help to enable the student to understand the successive steps of the simulation.

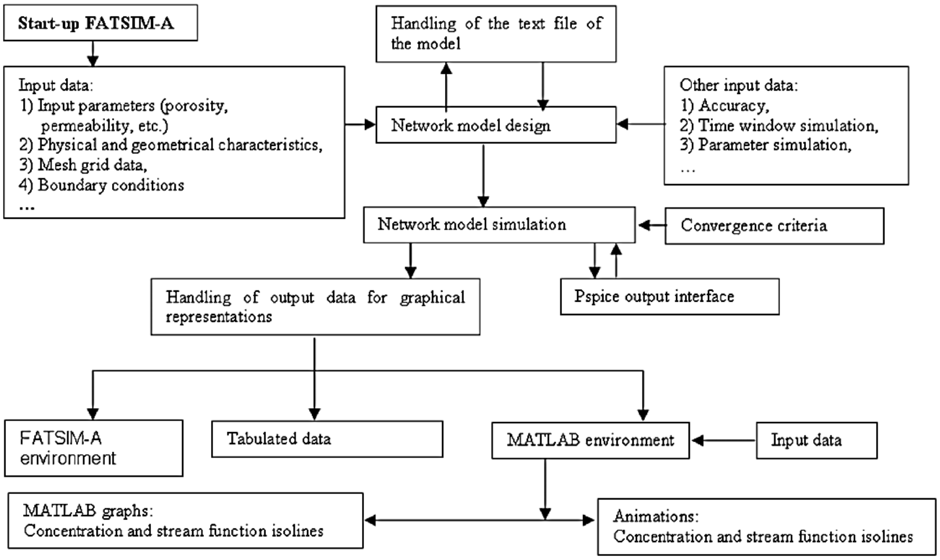


Fig. 1. Simplified flow diagram of the program.

FATSIM-A makes very easy for the students the introduction of data by an interactive grid window (layer name, hydraulic permeability, solute diffusivity, porosity and eventually, the parameters related with the grid size (number of cells and width and height of the cell), as well as the rest of the parameters needed for the simulation (minimum time step, time window of the simulation, relative tolerance of the calculus…). All the data are introduced as suitable screens such as that showed in Figure 2. Note, for example, that in the interactive grid each cell is specified by a group of four numbers: the two first refer to the horizontal position while the two last refer to the vertical (numeration of the cells begins at the left-bottom corner of the domain). A detailed numeration of the grid nodes, including the center of the sides of the volume element, is explained in the ‘‘Help’’ of the software.

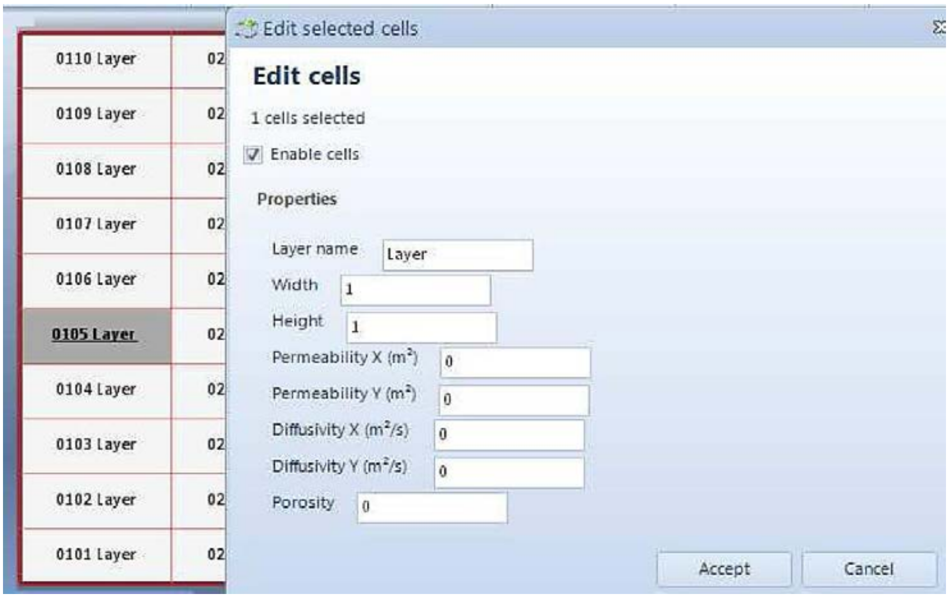


Fig. 2. Editing physical parameters of the media.

Once the model has been numerically solved in the Spice code, the screen ‘‘Simulation results’’ is shown. Isolines of concentration and stream function at any time can be shown in the same grid of the figure by selecting this information using the buttons Subcircuit and Time. Other auxiliary options for the picture can be selected in the same screen. The click of the button ‘‘Export’’ shows figures in MATLAB with greater accuracy. With this option the user can choose certain parameters of the representation, for example, the range and step of the isolines, the use of color and legend, etc. The option of ‘‘animations’’ can be activated with the button ‘‘Generate animation’’; a new screen is presented in order to ask the user for the animation parameters (mainly, time window and time step between pictures). After choosing these parameters, FATSIM-A starts up MATLAB to show the animation. The software contains many other possibilities common to commercial codes (e.g., saving all the generated files, alarms for values that are out of the range, direct handling of the text file of the model, view simulation progresses, etc.) [Alhama *et al.* (2011b)].

The reliability of the Pspice code has been verified by a large number of works in different fields of engineering, such as heat transfer, tribology, elasticity…, already published in the scientific literature. Particularly, the software FATSIM-A has been verified by solving standard benchmark scenarios such as Henry salt intrusion problem and Elder solute problem [Soto *et al.* 2007]. More detailed information about the software can be found in Alhama *et al.* (2011a) and Alhama *et al.* (2011b).

4. Classroom use: The study of Henry Problem

Master course of CIETAT devoted to water and soil engineering has been teaching since 2012 in the Universidad Politécnica de Cartagena with an average of 10 students per year. In the part of ‘Flow and transport in porous media’, at the beginning of the course, students are introduced to the system of equations governing the problem to solve. The first impression is of astonishment or absence of understanding of the meaning of the equations, though they are graduate students in engineering.

Many scenarios are proposed and solved in class. Figure 3 shows a rectangular domain in which a porous media contains a region of very high permeability where the flow or stream function lines intersect normally to its surface. It also shows a cavity which occupies the center of the aquifer and which tapers towards the continent.

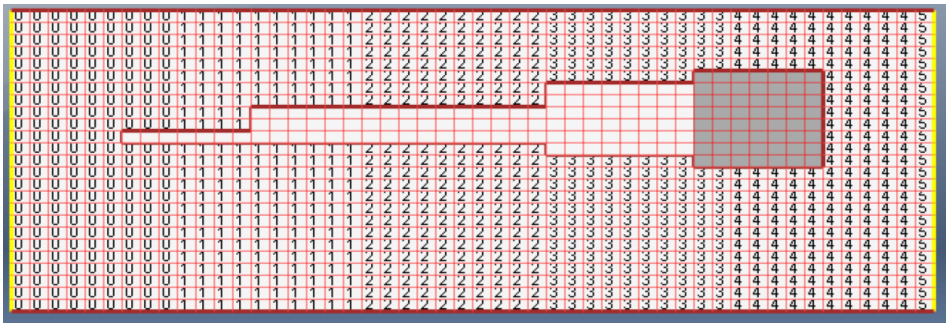
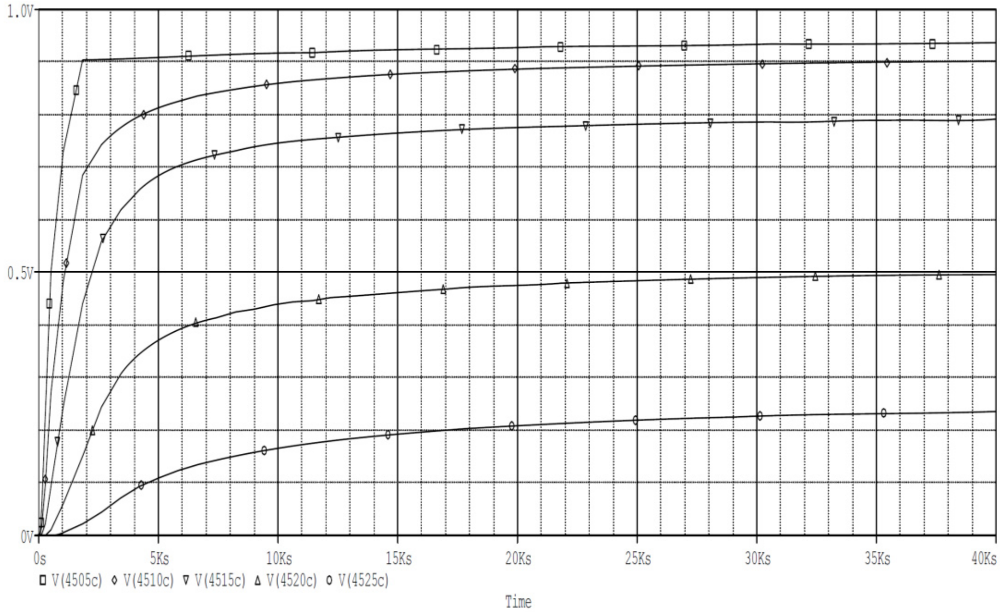
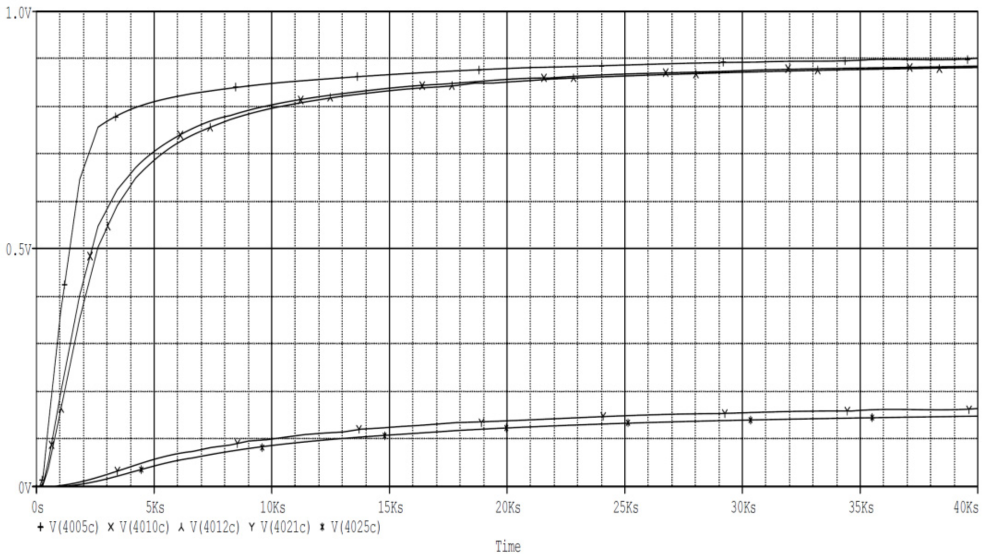


Fig. 3. Design of Henry scenario with cavity

In Figure 4 is showing the concentration versus time in typical vertical positions for two columns corresponding to the positions x = 1.8 m (cell 45, outside the cavity) and x = 1.6 m (cell 40, within the cavity). Students can observe the existing jump in the stationary concentration between positions above and below the cavity at x = 1.6 m.



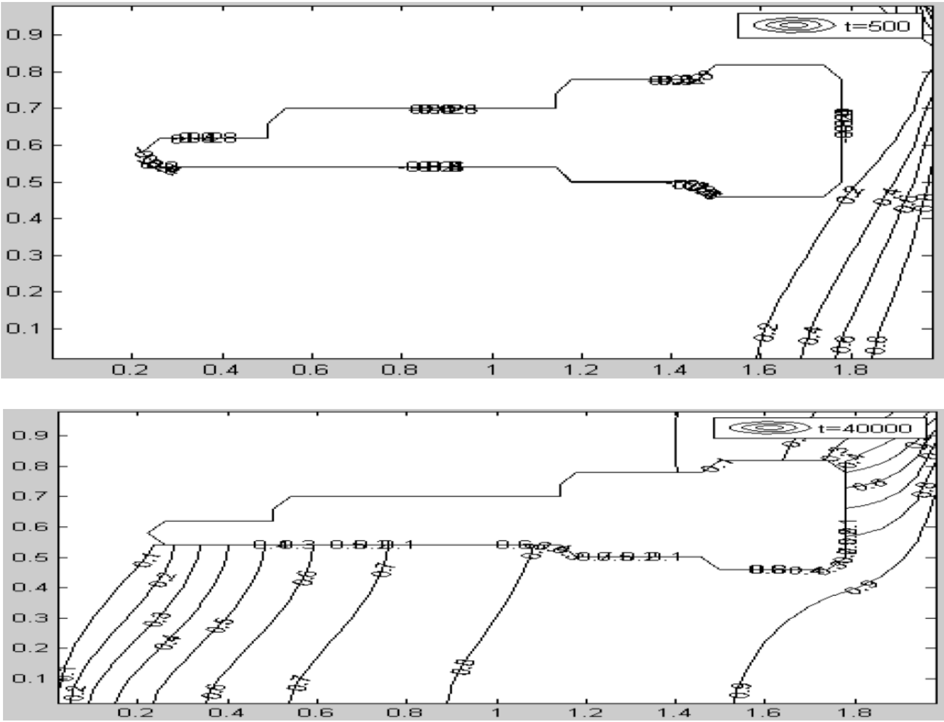
a)



b)

Fig. 4. Transient patterns of concentration of heterogeneous aquifer. Typical positions at a) x = 1.8 m and b) x = 1.6 m

In Figure 5, the student can see, at two different times, as the contaminated region delves into the continent at the bottom of the curve due to the shape of the cavity and remains virtually identical in the region above the cavity.



b)

Fig. 5. Transient patterns of concentration of heterogeneous aquifer. Concentration at a) 500s and b) 40000s

The best known benchmark problem that studies this process is the Henry problem, that it is proposed to students [Henry (1964)]. Salt water intrusion is a phenomenon in coastal regions where the salinity of the sea is higher than the salt content of the natural groundwater. The fresh water from the aquifer flows into the sea, while the deeper saline water penetrates inland, producing a saltwater wedge that extends from the sea at the bottom of the aquifer.

For a better understanding of the problem the student is posed a scenario with modifications of the standard problem. Once the problem is solved by the software (Figures 3 to 5), the student must interpret the results and their association with the govern equation: continuity, flow and solute transport and the constitutive Darcy equations. Finally, each student must explain the meaning of the solutions obtained with the software and the physical meaning of it. After some years teaching the master course, is had observed that this type of learning tools designed for a specific problem, facilitates the student's understanding of the problem. In addition, the presentation of results in a friendly system facilitates student understanding of the complex system of equations.

5. Conclusion

A powerful, versatile, and educational software, FATSIM-A, capable of application in research, has been developed for the numerical solution of fluid flow and solute transport processes. Characteristics of the commercial codes, such as communications with the user in a pleasant windows environment, selection of the mesh grid, capabilities of advanced programming, powerful graphic output screen to depict simulation results, etc., are installed in the software. Models designed by FATSIM-A of several sceneries implemented by students were explained to check his/her understanding of the problem.

References

Alhama, I. Soto A. and Alhama, F (2010) FATSIM-A (flow and transport simulator), Intellectual Property Registration, Murcia, Spain.

Alhama, I. Soto A. and Alhama, F (2011a), Flow and transport simulator FATSIM-A, In: Research and educational applications (in Spanish), Morpy, Servicio de Publicaciones de la UPCT, Cartagena.

Alhama, I. Soto A. and Alhama, F. (2011b) Fatsim-A: An educational tool based on electrical analogy and the code PSpice to simulate fluid flow and solute transport processes, Computer Application in Engineering Education, 22:3, pp. 516–528

Cerro-Velázquez, F. Gómez-Lopera, S. and Alhama, F. (2008) A powerful and versatile educational software to simulate transient heat transfer processes in simple fins, Computer Application in Engineering Education, 16, pp. 72-82.

Chapman, A. J. (1960) Heat transfer, Macmillan Publishing Company, New York.

Henry, H. R. (1964) Effects of dispersion on salt encroachment in coastal aquifers, in Sea Water in Coastal Aquifers, US Geol Surv Supp Pap 1613-C, 70–84.

Mills, A. F. (1999) Heat transfer, Prentice Hall, New Jersey.

Soto, A., Alhama, F. y González-Fernández, C.F. (2007), Density-driven flow and solute transport problems. A 2-D numerical model based on the network simulation method. Computer physics communications 177, 720-728 (2007).