Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Development of Numerical Modeling Environment for TOUGH2 Simulator on the Basis of Graphical User Interface (GUI)

Toshiaki Tanaka and Ryuichi Itoi

Department of Earth Resources Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan

tanaka@mine.kyushu-u.ac.jp

Keywords: numerical modeling, computer software, graphical user interface, three-dimensional visualization

ABSTRACT

An easy-to-use modeling environment for numerical geothermal reservoir has been developed for TOUGH2 simulator. It consists of pre-processors to prepare text-based input data, post-processors to visualize simulation result, and databases to store observations and information related to wells. These software have interactive graphical user interfaces for easy operation to develop numerical geothermal reservoir models, to execute TOUGH2 simulation, and to display simulation results with two and three-dimensional graphical views. The feature of the software and its usefulness are described with resulting views of example problems.

1. INTRODUCTION

The TOUGH2 simulator has great flexibility to be applied to problems in geothermal reservoir engineering, nuclear waste disposal, environmental assessment and remediation, and hydrology (Pruess, 1999).

The process creating complicated text-based input files for TOUGH2 simulations is often tedious and error-prone job for users. Computer programs for pre- and post-processing, such as Mulgeom and Mulgraph (O'Sullivan and Bullivant, 1995), Wingridder (Pan, 2003), GeoCad (Burnell at. al., 2003), G*Base (Sato et. al., 2003), PetraSim (Alcott et. al., 2006) were developed for solving these obstacles and free programs can be downloaded from the TOUGH2 web pages.

A new easy-to-use modeling environment has been developed to solve the problems above and also to be used for educational purposes. The software that runs on Windows system interactively has been coded by C++ programming language based on object-oriented programming technique with OpenGL (OpenGL Architecture Review Board, 2002) three-dimensional graphic library distributed by Silicon Graphics International (SGI). End users writing source codes based on the OpenGL are free from licensing requirements. Object-oriented programming technique enables us to improve and to enhance the software functions easily. The developed software provides integrated simulation environment using graphical user interfaces for TOUGH2. In particular, the graphical user interfaces of the software take advantage of the computer graphics to make TOUGH2 simulation easier to perform.

2. STRUCTURE OF SOFTWARE

The software consists of pre-processor, post-processor and some databases as shown in Figure 1. The pre-processor allows users to generate a text-based input data files for TOUGH2 by mouse operations with the graphical user interface. The post-processor can create various graphical views of charts, two-dimensional contour maps and three-dimensional isosurfaces from text-based output files of simulation results. Field data are stored in databases that include information related to geothermal wells such as well locations, trajectories and some logging results. The information can be inputted and stored into databases through a Well Data Window as shown in Figure 2.

Information store in the databases can be processed for visualizing valuable information about positions of feed zones and well locations, then users can easily define grid system in two and three-dimensional views as shown in Figure 3. Red solid circles indicate positions of feed zones at each well drawn in yellow line.

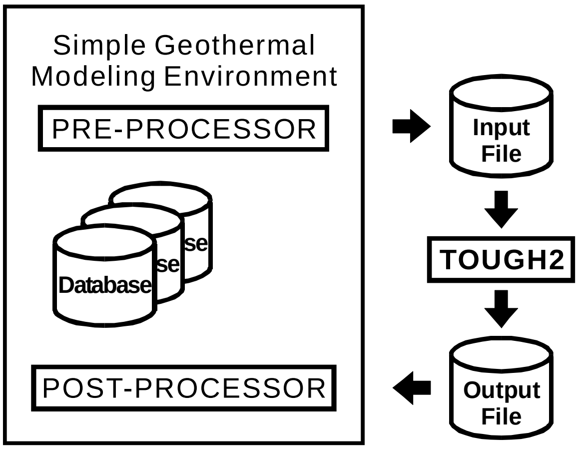

Figure 1. Schematic diagram of the easy-to-use modeling environment.

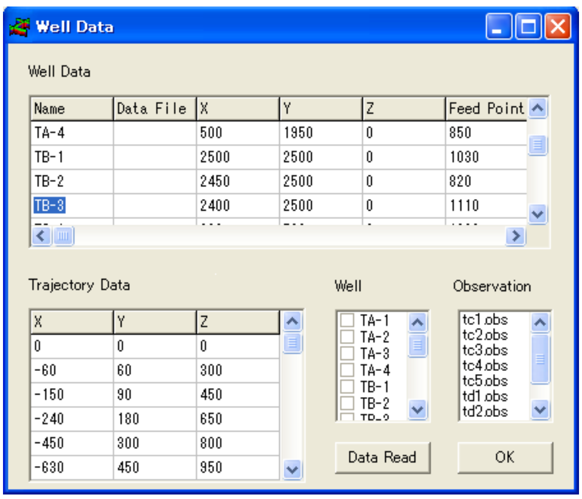

Figure 2. Well Data Window with trajectory data and observations obtained from wells in a simulation area to be stored into databases.

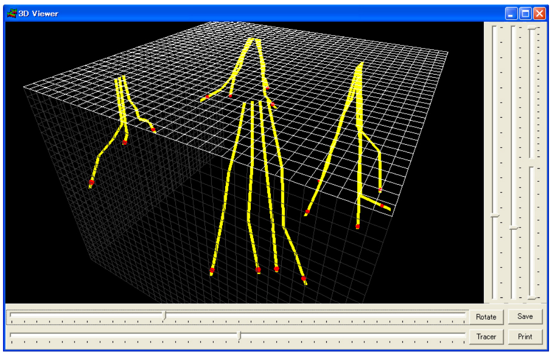

Figure 3. Three-dimensional view of trajectories of wells within a grid system.

3. SOFTWARE FEATURES

3.1 Pre-processor

The pre-processor provides two features that define geometric information as grid systems of a simulation area and generate various parameters for TOUGH2 simulation. The pre-processor can create three-dimensional rectangular grid system for a numerical model. A simulation area is defined by drawing a domain using a mouse on a topography map around the simulation area displayed on a computer screen. Then, considering geological structures, the number of grids, appropriate grid spacing, the number of horizontal layers and individual thicknesses are also specified from the window of Grid Editor.

After defining the grid system, the pre-processor generates text-based input data that contain information on elements and connections between elements.

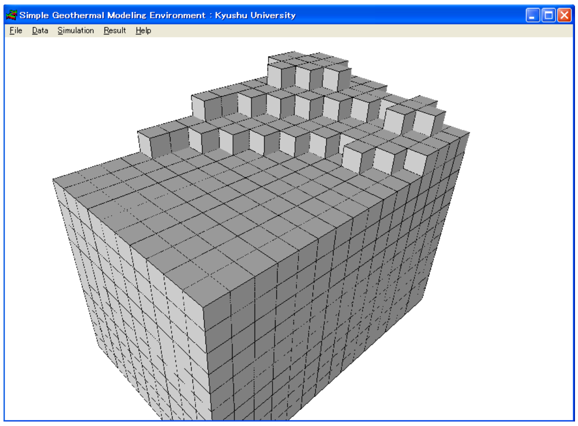

Figure 4. Example of a three-dimensional perspective view of a grid system defined by Grid Editor.

Figure 4 shows an example of a three-dimensional perspective view from arbitrary directions of a grid system displayed on a computer screen.

After creation of the grid system, the graphical user interface shown in Figure 5 also helps users to define rock property distributions on the color-coded editing plane with switching between plan view of a layer and a cross-sectional view. Rock properties can be assigned to individual elements by clicking the element with mouse or by dragging regions including adjacent elements on Rock Assignment Window as shown in Figure 5. Rock properties are defined in Material Property Editor and are stored in the Material Table (Figure 6).

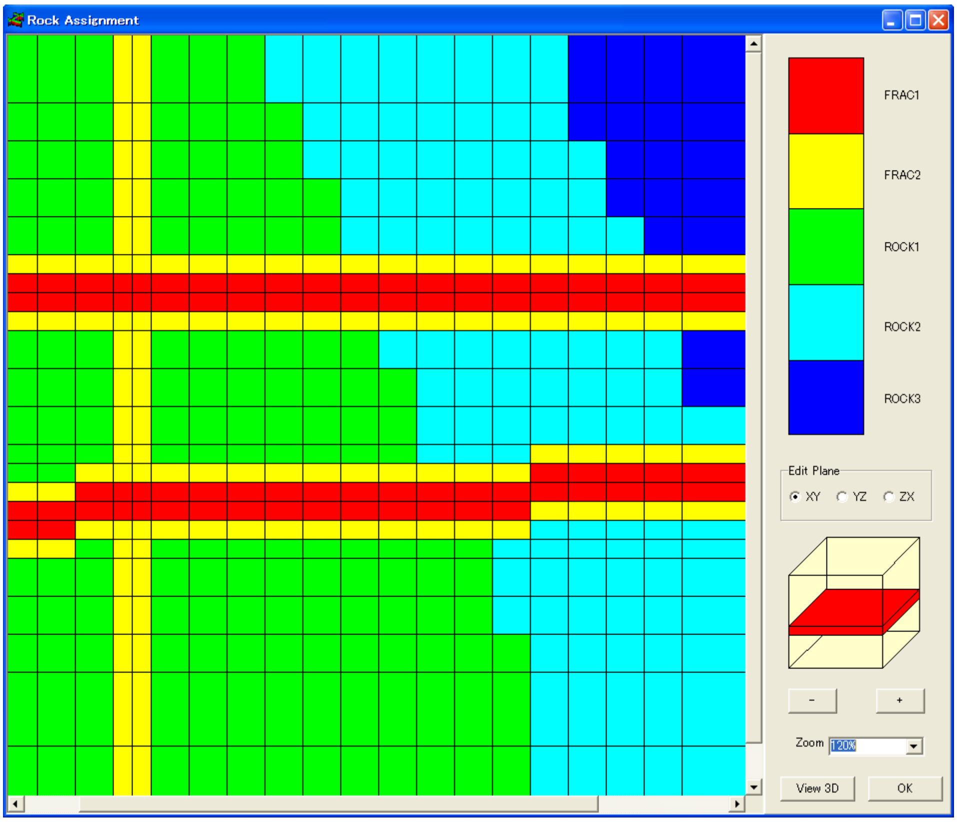

Figure 5. Rock Assignment Window displays plane view of color-coded rock distributions in a layer with the control panel on the right side of the window.

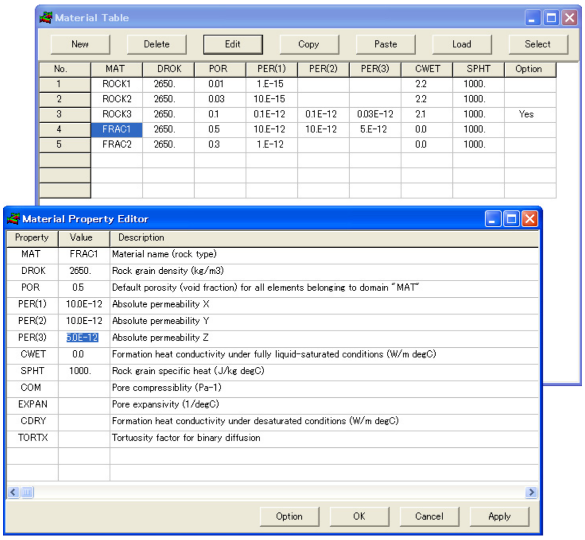

Figure 6. Screen of Material Property Editor and Material Table.

Other important simulation conditions, such as simulation parameters, initial conditions, boundary conditions, sources and sinks are defined with individual easy-to-use graphical windows in the same way.

3.2 Simulation Run

A TOUGH2 simulation is executed as a child process in the developed modeling environment. The simulation status during TOUGH2 simulation run is monitored on Status Window by the Simulation Control Facility of the software.

3.3 Post-processor

TOUGH2 produces text-based output file that store simulation results including information about simulation conditions and calculated values of various variables in each element and between elements at each time step.

The post-processor has an ability to visualize simulation results from complex TOUGH2 output files. In order to properly evaluate simulation results, various graphical plots can be made with the post-processor, such as two-dimensional contour maps, three-dimensional isosurfaces, two- and three-dimensional flow vector maps, and time plots.

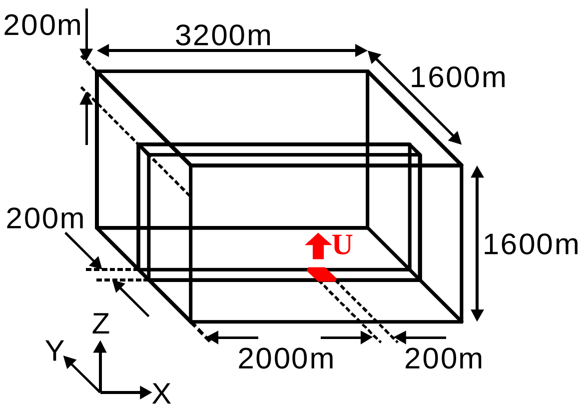

Figure 7. Schematic diagram of vertical fault bounded by low permeable rock. High temperature fluid is recharged from the bottom grid corresponding to up-flow zone U.

Table 1. Rock properties of the example model.

Rock type	Permeable Rock	Low Permeable Rock
Permeability (millidarcy)	100	0.1
Density (kg/m^3)	2500	2500
Specific heat (J/kg°C)	1000	1000
Thermal conductivity (W/m°C)	2.5	2.5

Table 2. Properties of the high temperature fluid.

Up-flow	
Flow Rate (kg/s)	20
Enthalpy (J/kg)	1085×10^3
Temperature (°C)	250

An example problem is designed to show the ability to visualize simulation results as illustrated in Figure 7.

The dimensions of numerical model for the example problem are 1600 m long, 3200 m wide and 1600 m deep. The model is divided into 16 elements for X and Y directions with 16 layers of the same element size of 100 m long, 200 m wide and 100 m deep.

The permeable vertical fault that is bounded by low permeable rocks is located at the center of the three-dimensional numerical model (Figure 7). Permeable fault with 200 m width is placed from 200 m deep from the surface to 1600 m. Rock properties used in the example problem are shown in Table 1. Permeability values of the permeable rock type that is assigned to the fault and the low permeable rock type are 100 millidarcy (1.0×10^{-13} m^2) and 0.1 millidarcy (1.0×10^{-16} m^2) respectively. Density of 2500kg/m^3, specific heat of 1000 J/kg°C, and thermal conductivity of 2.5 W/m°C are given to both rock types.

High temperature fluid of 250 °C (about 1085×10^3 J/kg) is injected from the up-flow zone, U, at the bottom of the fault at a constant flow rate 20 kg/s as listed in Table 2. Initial temperature and pressure of the model are 15 °C and 1 bar respectively.

Two- or three-dimensional graphical images of contour maps, isosurfaces, and flow vector maps of simulation results, in addition, well trajectories and observations can be managed individually as independent graphical objects in the software. The graphical objects can be overlaid simultaneously in three-dimensional Result Window at the specified time by selecting in the Time Steps table. Figure 8 shows a view of the Result Window of the simulation result of the example problem.

The three-dimensional view of Result Window shows temperature distributions of the simulation results at 4.0×10^{10} seconds (about 1.27×10^3 years). The three-dimensional view of the Result Window depicts vertical contour maps of the temperature distribution with the range from 15 to 273.6 °C on the sliced plane along the vertical fault, and an isosurface at the temperature of 200 °C around the top of the fault.

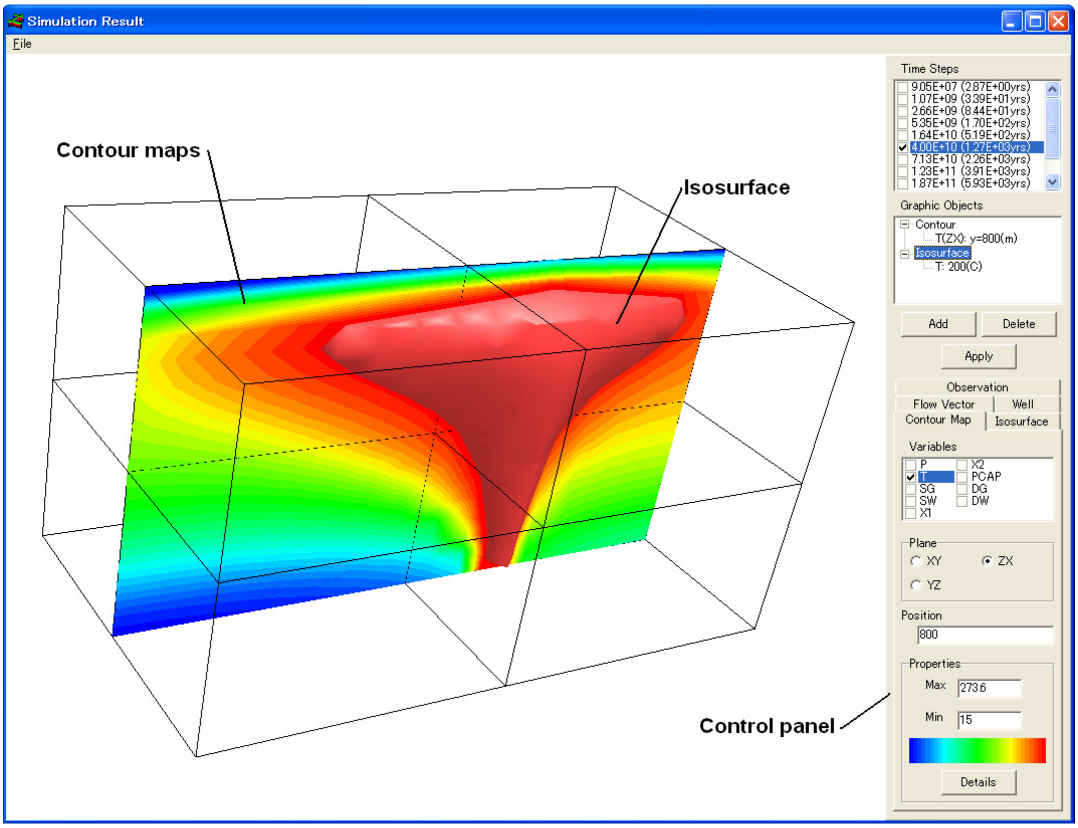

Figure 8. Example of a three-dimensional view of simulation results showing temperature distribution along the vertical fault by two-dimensional contour maps and an isosurface at the temperature of 200 °C.

The T shaped high temperature region above 200 °C depicted by the isosurface suggests the formation of convective flow with high temperature fluid recharged from the bottom grid corresponding to the up-flow zone, U.

4. CONCLUSIONS

The simple geothermal modeling environment has been developed. The software has interactive graphical user interfaces that are easy to perform geothermal reservoir simulations with TOUGH2. It consists of pre-processors to prepare text-based input data, post-processors to show simulation result graphically, and databases to store observations and information related to wells.

REFERENCES

Alcott, A., Swenson, D., and Hardeman, B.: USING PETRASIM TO CREATE, EXECUTE, AND POST-PROCESS TOUGH2 MODELS, PROCEEDINGS of TOUGH Symposium 2006, Lawrence Berkeley Laboratory, Berkeley, CA, (2006).

Burnell, J.G., White, S.P., Osato, K., Sato,T.: GeoCad, A PRE- AND POSTPROCESSOR FOR TOUGH2, PROCEEDINGS of TOUGH Symposium 2003, Lawrence Berkeley Laboratory, Berkeley, CA, (2003).

Finsterle, S.: iTOUGH2 User's Guide, Report LBNL-40040 Lawrence Berkeley National Laboratory, University of California, Berkeley, CA (2000).

OpenGL Architecture Review Board: OpenGL Programming Guide, The Official Guide to Learning OpenGL, Version 1.1, Pearson Education Japan (2002).

O'Sullivan, M.J. and Bullivant, D. P.: A graphical interface to the TOUGH2 family of flow simulators, PROCEEDINGS of TOUGH Workshop 1995, Lawrence Berkeley Laboratory, Berkeley, CA, (1995).

Pan, L.: WINGRIDDER ---- AN INTERACTIVE GRID GENERATOR FOR TOUGH2, PROCEEDINGS of TOUGH Symposium 2003, Lawrence Berkeley Laboratory, Berkeley, CA, (2003).

Pruess, K., Oldenburg, C. and Moridis, G.: TOUGH2 User's Guide, Version 2.0, Report LBNL-43134, Earth Sciences Division, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA (1999)

Sato, T., Ohsato, K., and Shiga, T.: G-STAR-BASE (G*BASE) —A DATA BASE SYSTEM FOR UNDERGROUND INFORMATION AND POST-PROCESSING FOR TOUGH2, PROCEEDINGS of TOUGH Symposium 2003, Lawrence Berkeley Laboratory, Berkeley, CA, (2003).