Future Directions in Geothermal Modelling

12 June 2013  Mike O’Sullivan
Outline of the presentation

- My wish-list for developments in geothermal modelling techniques, including some discussion of future research directions
My wish-list categories

- Conceptual modelling
- Computer model design
- Wellbore-reservoir interaction
- Larger, deeper models
- Model calibration and uncertainty estimates
- Fluid-rock interaction
- Numerics
- Near-surface behaviour, surface features
- Model organisation, version control etc
- Data
Better integration of diverse data, preferably in a common graphical interface.

Perhaps LEAPFROG is the answer

**Wish #1:** Good conceptual modelling tools
Model design

- Better tools for grid design, mesh generation etc
- Better tools for showing how the model grid fits the conceptual model and various data
- Fitting topography
- Showing well locations
- Interpolating from one model on to another
- pyTOUGH, MULGRAPH etc

Wish #2: a complete set of easy to use tools for model design and creation
Wellbore-reservoir interaction

- There has been some work on coupling a wellbore model with TOUGH2 (Hadgu et al., 1995; Bhat et al., 2005)
- TOUGH2 provides a simple multi-layer well on deliverability option
- Also TOUGH2 provides a single-layer complex deliverability model

\[ q_\beta = \frac{k_{r\beta}}{\nu_\beta} PI(p_\beta - p_{wb}) \]

\[ P_{wb} = f(q_m, h_f; P_{wh}, z, r_w) \]

Table look-up
Wellbore-reservoir interaction

- **Wish #3**: A better multi-feed wellbore/reservoir model
- Perhaps a 1D solve of a steady wellbore model could provide coefficients for a multi-layer deliverability model
Larger, deeper models

Present model zone

Wish #3 model zone
Larger, deeper models

**Require:**
- Good EOSs that can handle high PT (e.g. Kissling and Croucher and O’Sullivan for pure water, Kissling for H2O/NaCl).
- **Wish # 3:** An EOS for H2O/CO2/NaCl that can handle a full range of PT.
- Better understanding of deep reservoir physics.
Model calibration

We use:

- Manual methods - too time consuming, too dependent on the modeller.
- Inverse modelling (iTOUGH and PEST) – OK but requires a lot of manual intervention
- Statistical sampling Multi-chain Monte Carlo methods (MCMC) – too slow
Wish #4 (a,b,c,d):

- An expert system approach to manual calibration codifying steps taken by a modeller.
- A guiding program for iTOUGH and/or PEST that will make decisions about parameter selection, subdivision of rock-types, re-assignment of rock-types etc
- Faster MCMC methods
- Better visualisation tools (MULGRAPH, pyTOUGH, Petrasim, LEAPFROG?)
Automated calibration offers the possibility of making formal uncertainty estimates with future scenarios.

Investigate parameter nullspace using Monte Carlo methods or use MCMC for whole process.

Wish #4: Formal uncertainty estimates.
Fluid-rock interaction

- Some work has been carried out already coupling TOUGH2 and FLAC3D (Rutqvist and Tsang (2003) and Pruess et al (2004)).
- We have used TOUGH2 and ABAQUS to model subsidence at Wairakei-Tauhara.
- George Zyvoloski’s FEHM has been used for hot dry rock simulations, including fluid-rock interaction (Tenma et al., 2008).
Fluid-rock interaction

Model results for the Wairakei subsidence bowl.
Fluid-rock interaction

More needs to be done on:

- Spreading of fracture networks as a result of hydraulic fracturing (Wish #6)
- Fluid movement and rock behaviour at depth near and below the brittle-ductile transition.
Fluid-rock interaction

- Coupling of TH & M?
- Constitutive models for rock mechanics? Linear elastic or what?
- Constitutive model for stress state, fracture opening, porosity and permeability?
Numerics

- Reliable and quick simulation of natural states. Requires improved linear equation solvers.
- Parallelisation of TOUGH2 and iTOUGH (well underway – much work at LBNL over the last decade)
- Improved accuracy via Euler-Lagrange methods – would require some structure on TOUGH2 grids.
Wish #7: A suite of 16 core workstations running parallel versions of TOUGH2 and iTOUGH with a complete range of EOSs.

Wish #8: Improved linear solvers

Wish #9: Implementation of Euler-Lagrange methods into a 3D multi-phase version of TOUGH2
At Wairakei-Tauhara there are several issues arising from the interaction of the deep reservoir and the near surface zone.

We use an air-water version of TOUGH2 to include the unsaturated zone in an approximate fashion (our minimum layer thickness is 50m).

We need a moving water table (or “steam” table) approach.

Related to the need to better represent surface features (steaming ground, hot springs, geysers).
Near surface behaviour

- **Wish # 10**: An option allowing for a vertically moving interface within a block.
- With the interface separating the unsaturated zone and saturated zone.
- This is tricky in the geothermal context because the saturated zone can be filled either with hot water or steam, or a mixture of both.
Surface features

- Represent surface features by wells on deliverability or flow up a column to the surface
- Not really satisfactory
- **Wish # 11**: Better ways of dealing with surface features
Wish # 12: Better model organisation
Perhaps use a script that contains:
1. Comments on the simulation
2. Identification of the simulator used
3. Basic model file name (ELEME, CONNE, ROCKS)
4. File with production and injection wells
5. File with “boundary condition” wells
6. Time step control file
7. INCON file
Data

- **Wish # 13**: Better data
- Down-hole temperatures – OK but often interpretation is needed.
- Mass flows – Not always measured well-by-well
- Enthalpies – Usually OK but better accuracy would be nice
- Pressures – the least satisfactory kind of data. Where measured? What do well pressures tell you about reservoir pressures? Water levels vs Pressure?