Efficient Fossil Energy Technologies Engineering Doctorate (EngD) Centre

The University of Nottingham UNITED KINGDOM · CHINA · MALAYSIA

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Research Councils UK Energy For a Low Carbon Future

Modelling the Environmental Impact of Underground Coal Gasification

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clean coal syngas

UCG and the Environment

	Global	Local
Positive	• Efficiency Gains • Easy CCS Coupling • Safety of Miners	• Less Dust / Ash • Small Surface Footprint • Fewer Heavy Metals etc.
Negative	• Coal is a Finite Resource • CCS Dependency	• Ground Subsidence • Groundwater Pollution • Groundwater Depletion

Previous modelling efforts

Author	Reactions	Heat and Mass Transfer	Cavity Growth	Subsidence	Groundwater	Notes
Thorsness (1977)	Single reaction	Convection only	Reaction only	Not modelled	Not modelled	First published
Biezen (1995)	Not modelled	Not modelled	Complete	Not modelled	Not modelled	Arbitrary cavity shape
Perkins & Sahajwalla (2008)	Fully derived kinetics	Convection and Radiation	Not modelled	Not modelled	Not modelled	Kinetics used by many since
Morris (2009)	Not modelled	Not modelled	Collapse only	Explicitly Modelled	Not modelled	Cavity shape input
Nitao (2011)	Fully derived kinetics	Convection and Radiation	Complete	In progress	In progress	Suite of submodels

- Almost all models derived for small, pilot scale operation
- Few models consider subsidence or groundwater issues
- **No models consider subsidence and groundwater simultaneously**

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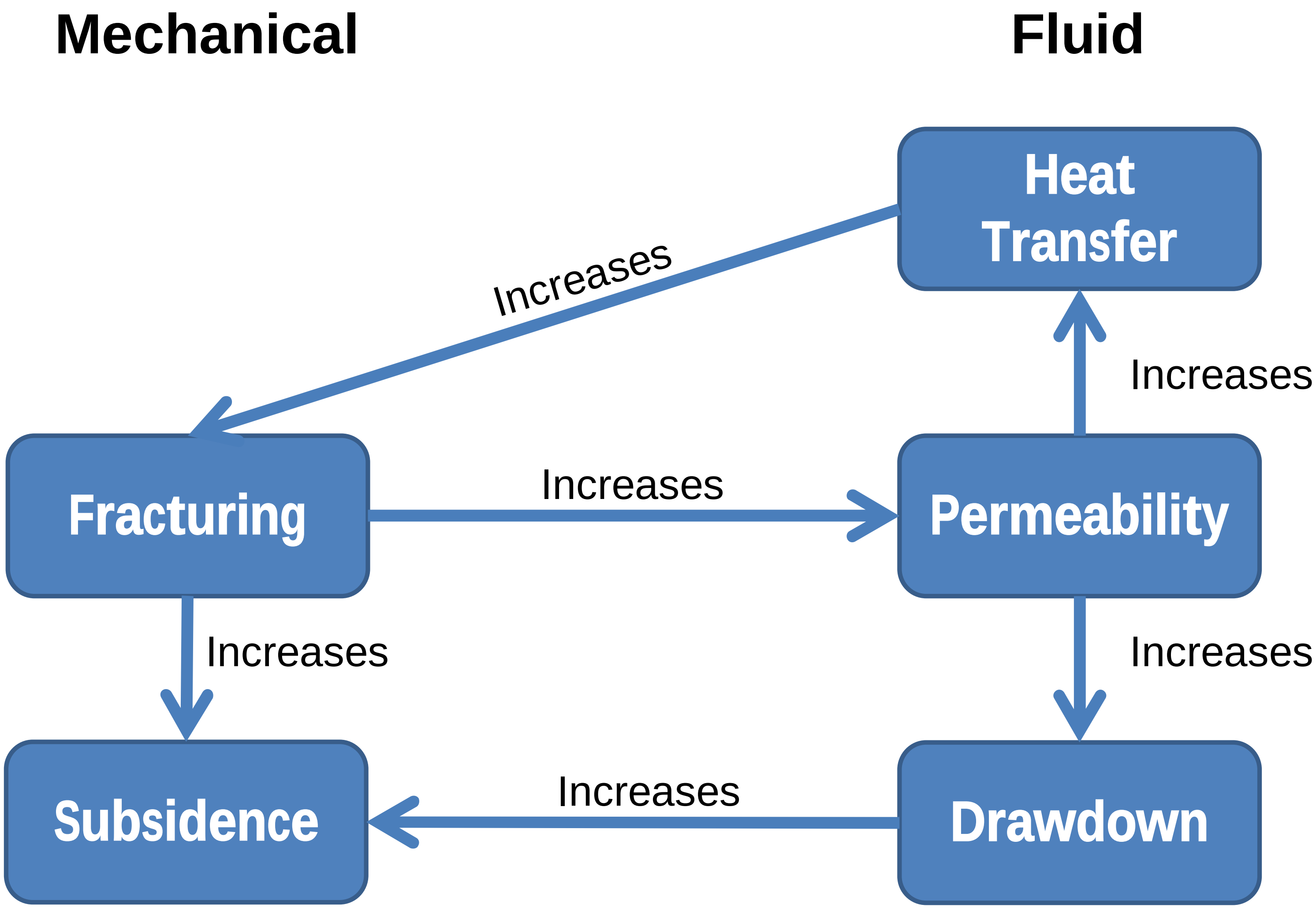
Fluid-Mechanical Coupling



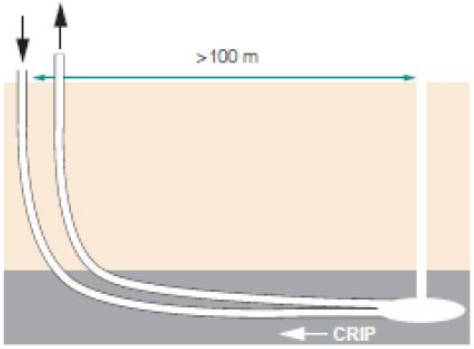
Model Aims

- To predict the local environmental impact of UCG, including:
  - Surface subsidence
  - Groundwater pollution
  - Groundwater depletion

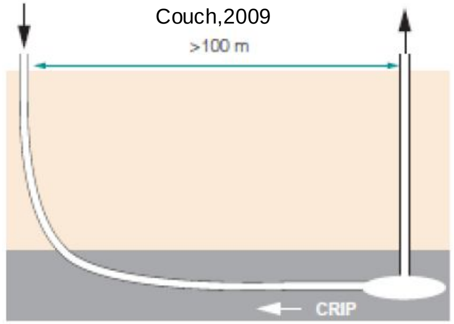
- To operate over a range of scales and gasifier designs

- To operate on a general (non site-specific) basis

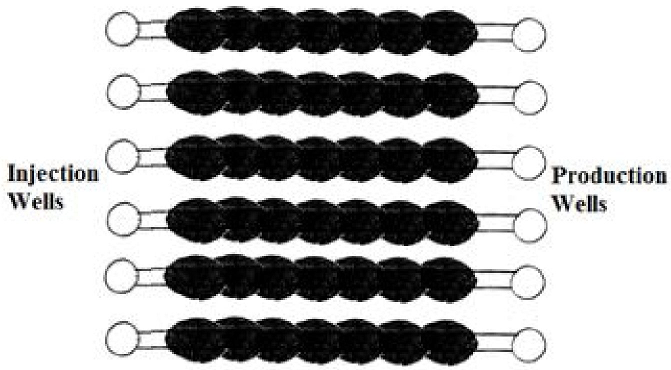
- To run within a few days on a desktop PC



Couch,2009



Couch,2009

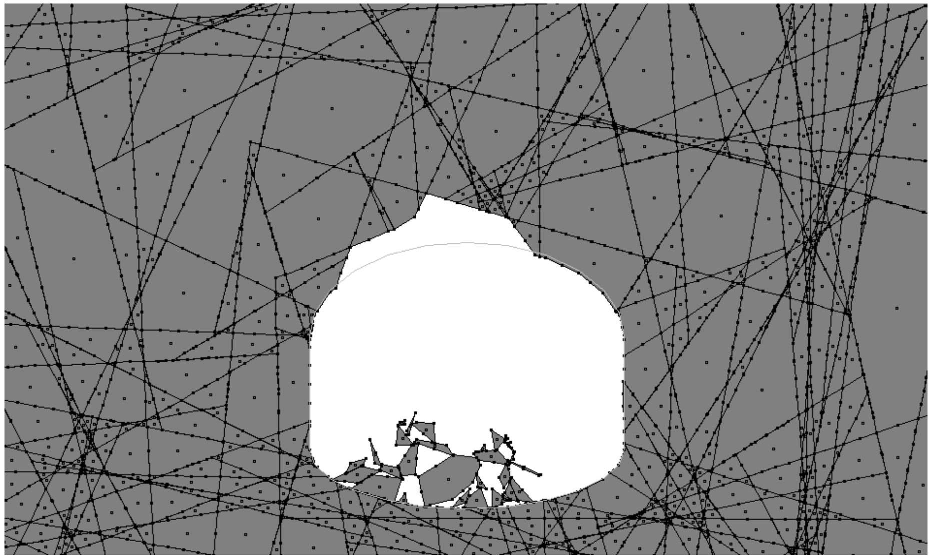


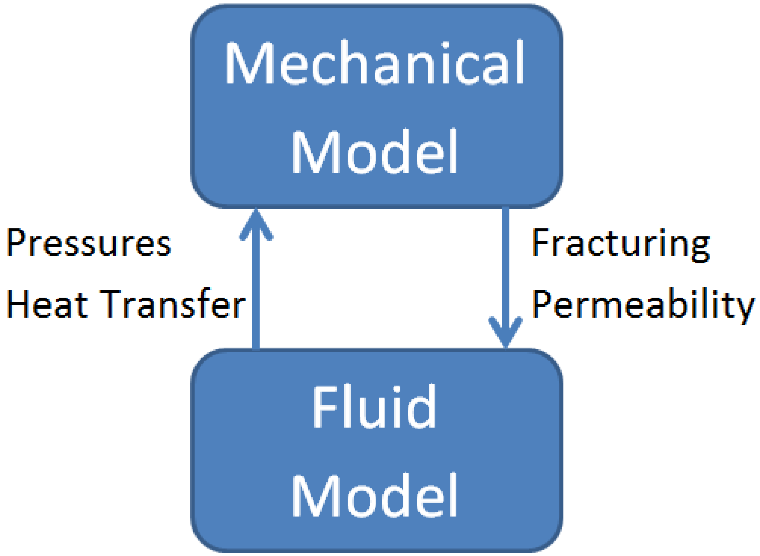
The model will be used as a “first pass” to determine suitability of various sites and gasifier designs. Chosen designs will then undergo more thorough analysis.

Methodology

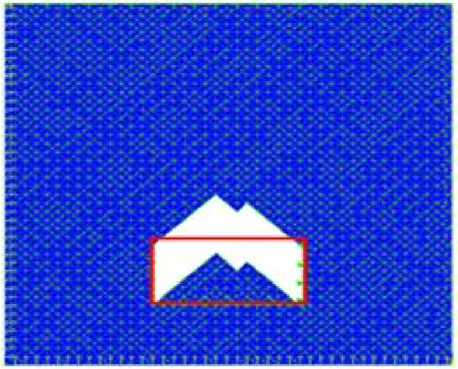
- Discrete Element Method (DEM) used to model rocks surrounding coal seam
  - Predict motion of blocks from coal seam to ground surface
  - Model fracturing in regions surrounding cavity – determine permeability

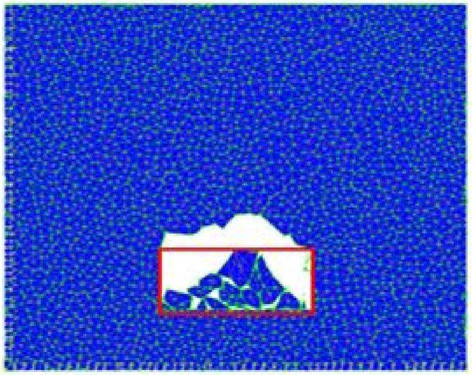
- Finite difference code used to model groundwater flow in joints between rocks
  - Pore pressure tracked to show developing cone of depression
  - Contaminant dispersion and advection modelled through fluid
  - Possibility of modelling heat transport

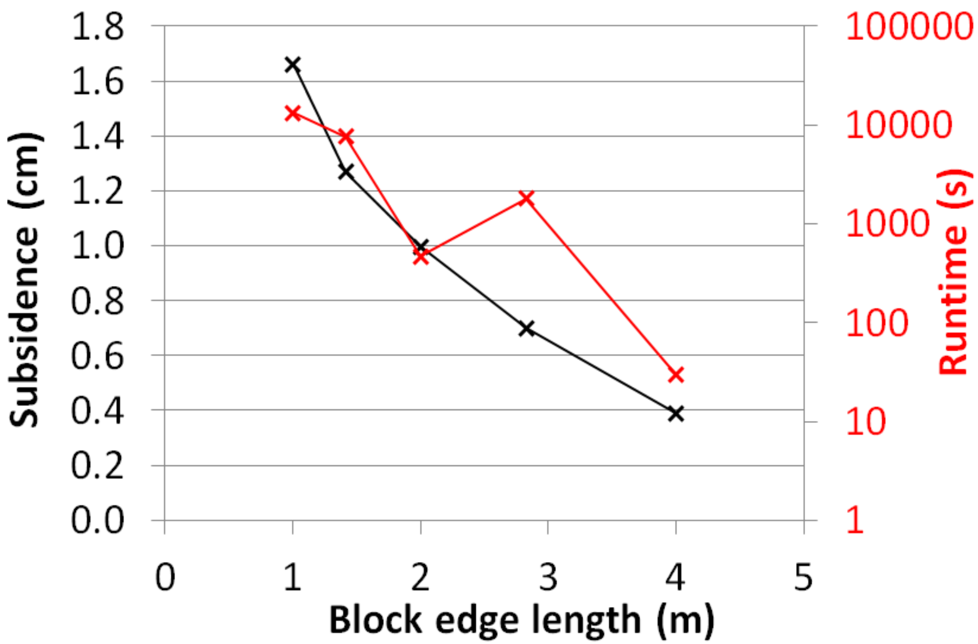




Effects of block size and shape



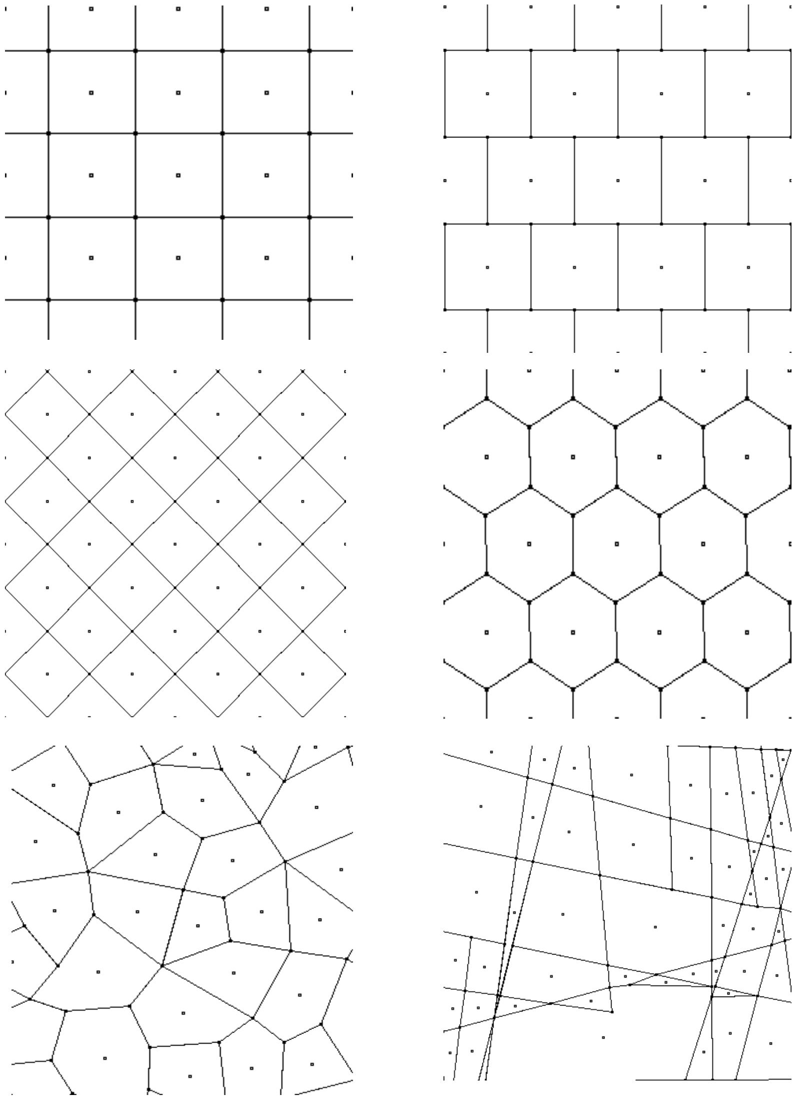




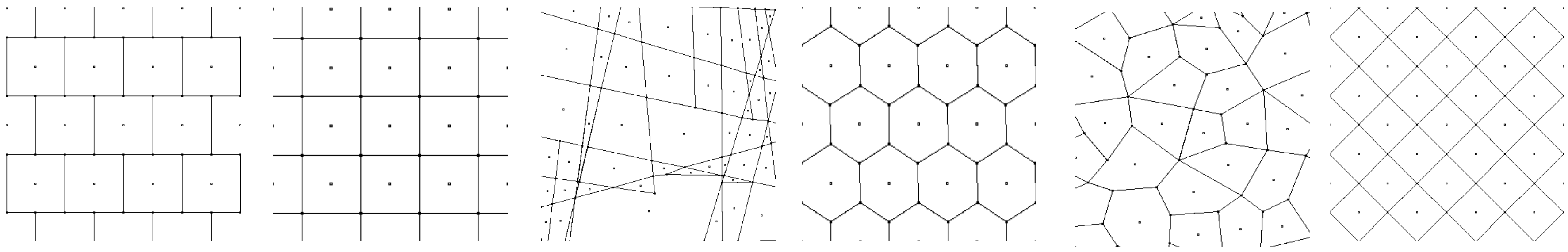
- Regular patterns give unrealistic failure shapes
  - Current random pattern based on Sellafield data
- Size and shape of the modelled rocks greatly affect results
  - Smaller rocks = Longer runtime
  - Smaller rocks = More subsidence
- Real rocks are too small to model.
- Each modelled rock represents an assembly of hundreds of real rocks

Simulated Triaxial Testing

- 4 periodic patterns and 2 irregular patterns studied
- Constant length and perimeter/area ratios throughout all geometries
- Effects of block size and interface properties investigated
- Elastic, peak stress and dilative behaviour studied
- Results used to fine tune material properties for UCG model



Overall Influence of Shape



Strength

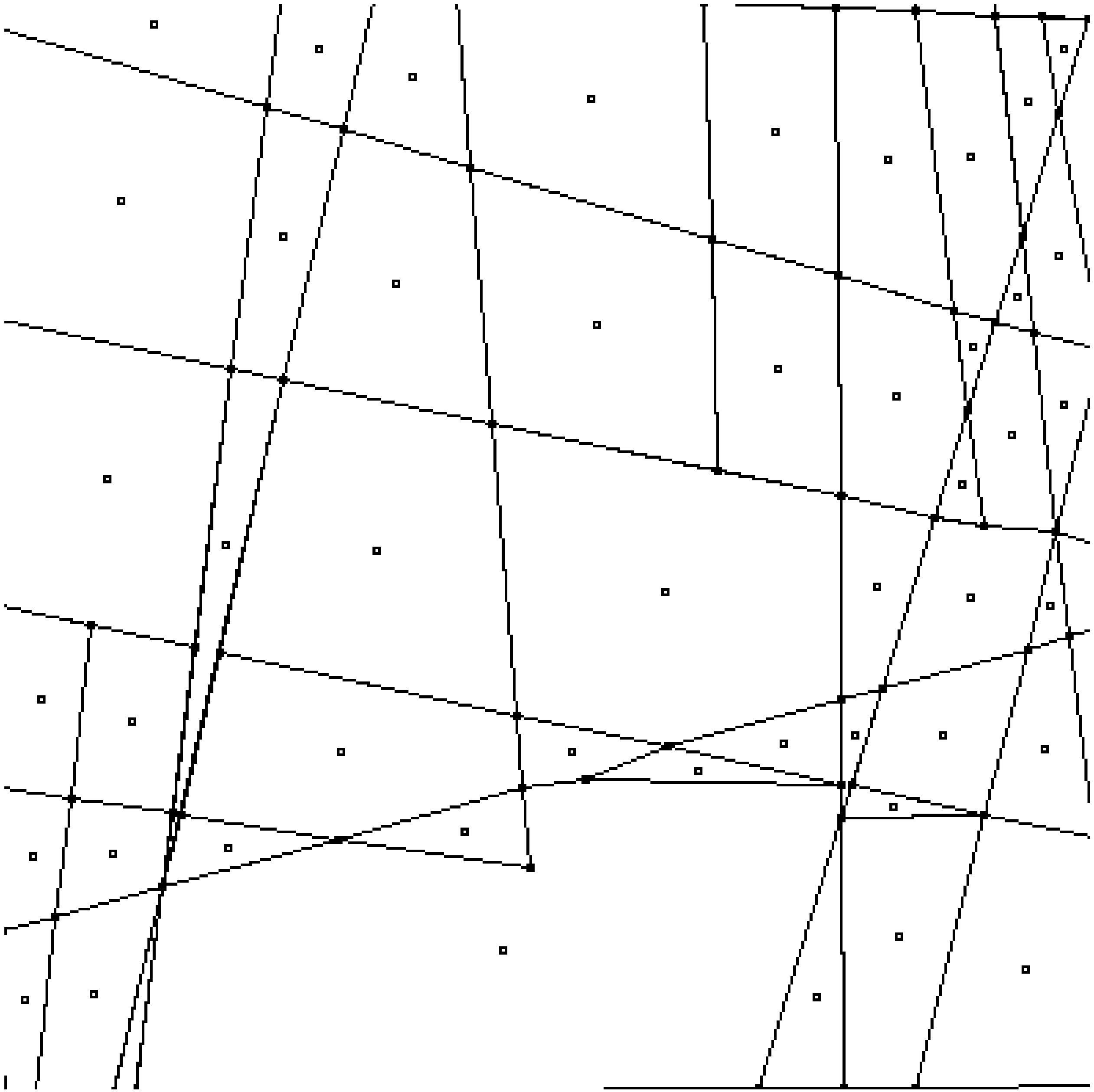
Brittleness

Dilation

Because

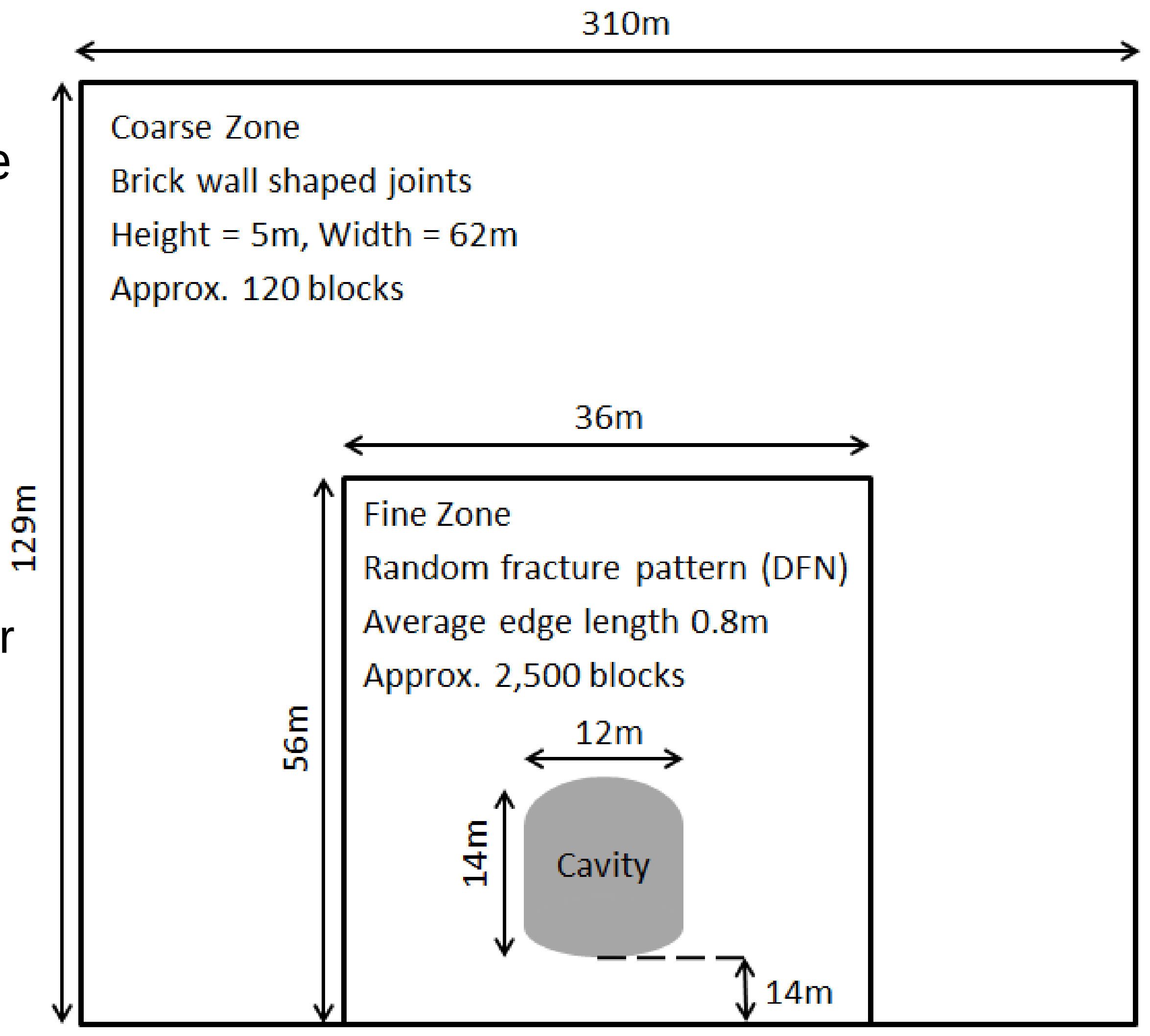
Angle between joint and applied force

Number of joints



Model Design

- Geometry based on RM1 site
- Model broken into coarse and fine mesh
  - Retains accuracy
  - Reduces number of blocks by a factor of 20
  - Reduces runtime by a factor of 200!
- Runtime approx. 48 hours



Initial Subsidence Modelling

- Initial models assumed no fluid flow
  - Subsidence due roof collapse only
- Results are compared to empirical predictions based on UCG experience
  - Field trial data is hard to find
- Recent work investigates effect of site design parameters:
  - Cavity depth
  - Cavity width
  - Cavity height
- Dry model runtime approx. 12 hours
- Stochastic block shapes introduce random variation into model results

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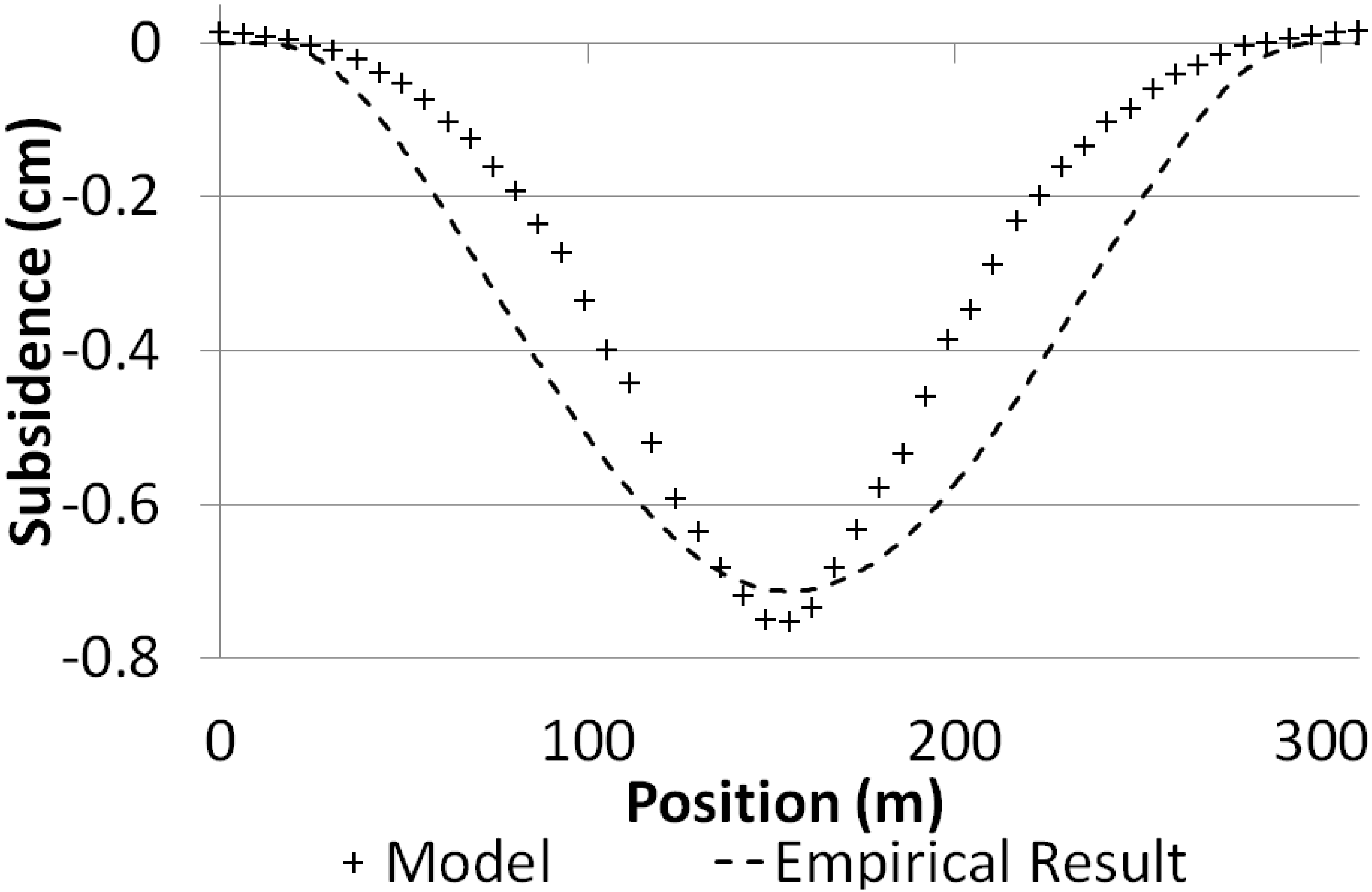
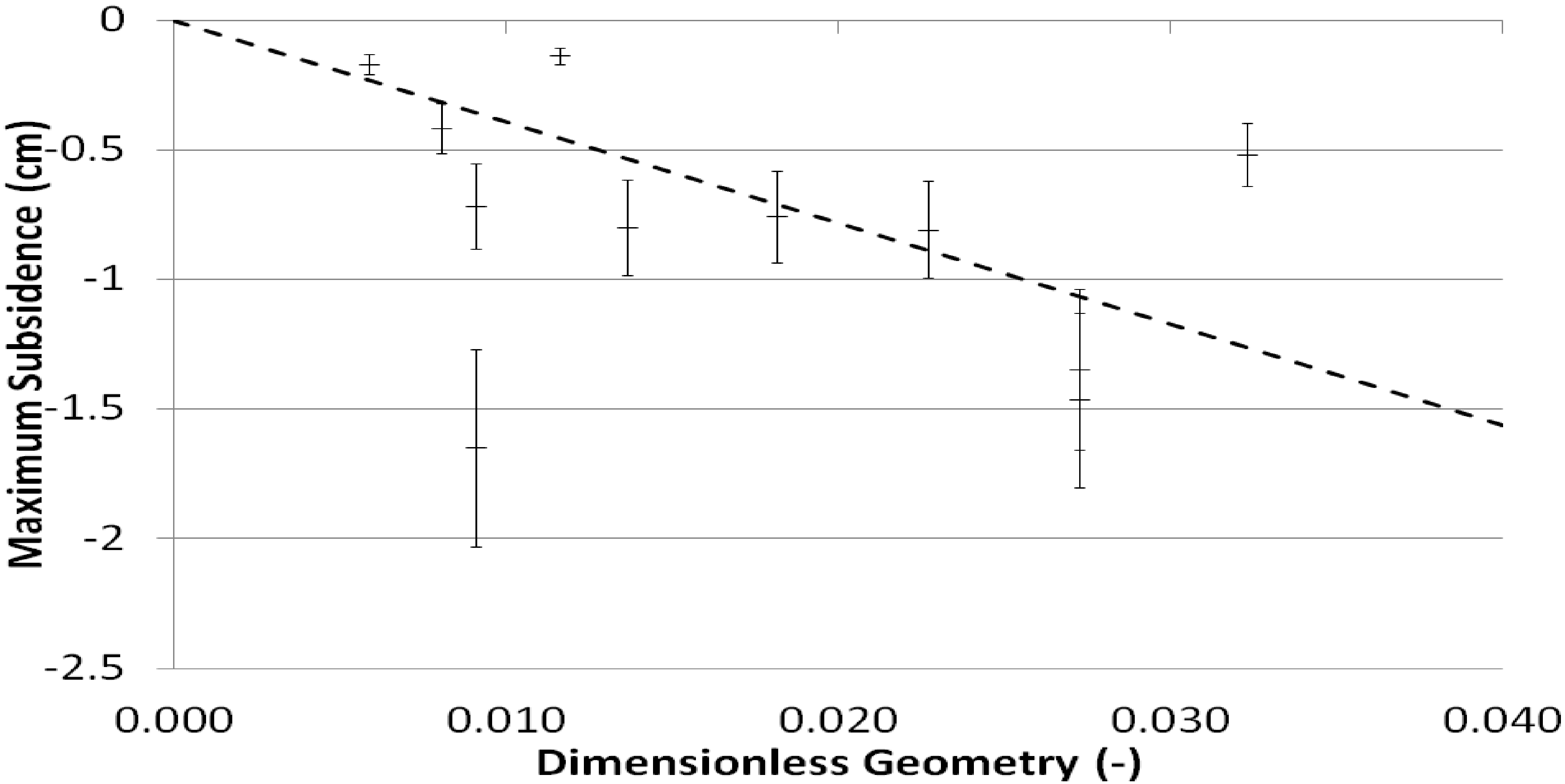
Surface Subsidence Profile



Subsidence Predictions

- Empirical relation predicts $S \propto \frac{WH}{D^2}$
- Highly variable results with some large outliers



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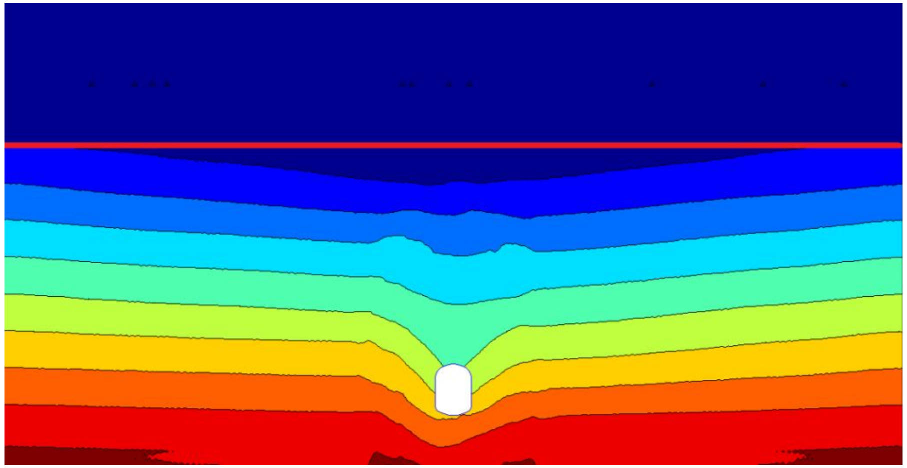
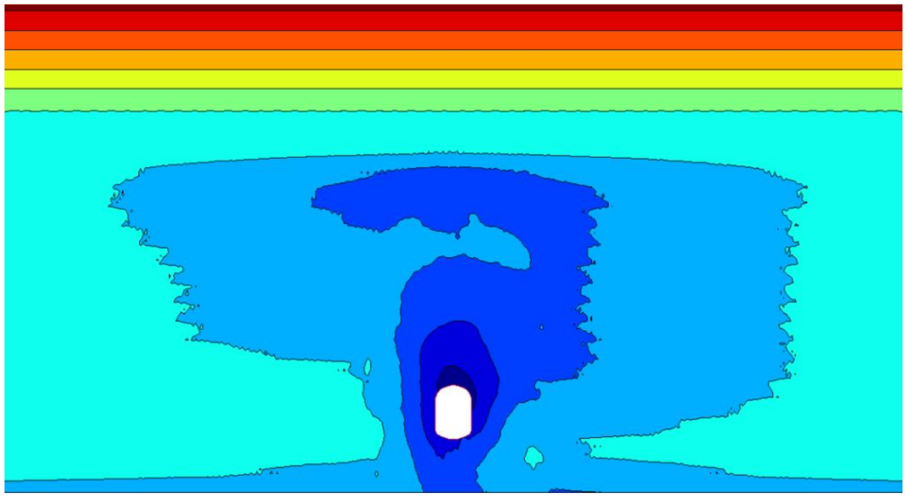
Initial Fluid Modelling



Pressure Distribution



Equipotential

- Model simulates flow through joints
  - Intact rocks assumed impermeable
- Model outputs pore pressure distribution and equipotential surface
  - Cone of depression forms around cavity
- Existence of fluid flow exerts an extra downwards force, increasing subsidence compared to dry system
- Two new input variables
  - Water table height
  - Cavity operating pressure

Long Term Plans

- Finalise fluid model
- Incorporate simple rates for contaminant generation and transport
  - Coupled diffusive and advective transport model
  - Production rate dependent on cavity wall area
  - Removal via flushing into cavity
- Side collaboration with NCG on heat transport and cavity growth model for COGAR project
  - Possibility of combining with subsidence / contamination model
- Compare results of integrated model over a range of multiple cavity geometries and local geology/hydrogeology conditions to provide guidelines for expected behaviour of varying sites

Challenges

- Flow field and rock deformation much more coupled than we first thought
  - Enforced water drawdown causes increase in deformation
  - Large ground movements cause large pressure fluctuations

- Scale issues - looking for 1mm displacement over 100m of depth
  - High model resolution needed
  - Hard to measure such small motions in the field
  - General lack of data on subsidence at previous field trials

- Validation of results – field data is hard to find
  - No previous commercial scale operation to compare to
  - Previous trials publish little on subsidence
  - Single cavity gives no indication of how cavities interact
  - Large tunnels/mines have similar shape, but much less water drawdown

Thank You for Your Attention

With thanks to CleanCoalSyngas ltd and the EPSRC for their support with this research.

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EPSRC
Engineering and Physical Sciences Research Council

References

Biezen, E.N.J. (1996): Modelling Underground Coal Gasification. PhD thesis. *Delft University of Technology*, The Netherlands.

Couch, G.R. (2009): Underground coal gasification. *IEA Clean coal centre* 2009.

Morris, J.P., Buscheck, T.A., Hao, Y. (2009): Coupled geomechanical simulations of UCG cavity evolution. Presented at *the twenty-sixth annual international Pittsburgh coal conference.* Pittsburgh, PA.

Nitao, J.J., Camp, D.W., White, T.A., Burton, G.C., Wagoner, J.L., Chen, M. (2011): Progress on a new integrated 3-D UCG simulator and its initial application. Presented at *International Pittsburgh Coal Conference.* 22nd September 2011, Pittsburgh, PA.

Perkins, G., Sahajwalla, V. (2008): Steady state model for estimating gas production from underground coal gasification. *Energy & Fuels* 22, pp 3902-3914

Thorsness, C.B., Rozsa, R.B., Wong, R. (1977): Two-dimensional modelling of in-situ coal gasification. Presented at *the 3rd Annual Underground Coal Conversion Symposium,* California.