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Request:            Any publications relating to “Underground Coal Gasification” which have been drafted by or released by the CSIRO or written by another entity which sourced resources or collaboration or input from the CSIRO.
Document(s):        1-5

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Underground Coal Gasification (UCG) in Australia

Cliff Mallett & Andrew Beath
Sustainable Mining Research Group
CSIRO Exploration and Mining
UCG in Australia
CSIRO Exploration and Mining

- Real-time UCG modelling
  - Development of a 3D modelling tool to
    - Assist in site design
    - Predict the progress of UCG cavity growth
    - Optimize product gas quality

- Process modelling
  - Design of UCG processes with reduced environmental impact
  - For example, processes with integrated carbon dioxide sequestration
UCG in Australia
CSIRO Exploration and Mining

- Cavity growth predictions
UCG in Australia
CSIRO Energy Technology

- CFD modelling of UCG
  - Detailed modelling of UCG cavity growth using a commercial fluid flow modelling package (FLUENT)
  - Includes modelling of gas flows in the gasification cavity and through porous materials
UGC in Australia
CSIRO Energy Technology

- Example CFD model output - Temperatures

Temperature Profiles:

Max. Temp. ~1400K

Axial slices

High temperatures on cavity roof and sidewall.

Areas of most intense reaction and highest coal consumption

On plane of symmetry
UCG in Australia
Commercial activities

- **Linc Energy**
  - Started trial in Dec 1999
  - 3-hole UCG site
  - Coal depth ~170m
  - Seam thickness 5-8m
  - Air-blown
  - Low calorific gas produced
  - Next stage a 40MW plant
  - Currently evaluating 6 sites
UCG in Australia
Concluding remarks

- **Summary**
  
  - CSIRO is currently undertaking UCG modelling research using two different approaches
  
  - Commercial UCG developments are advancing past preliminary trials towards a small scale demonstration
Key note Speaker

**Burl Davis** is recognized worldwide for work in Underground Coal Gasification Technology. He is an expert in coal conversion technologies including, coal gasification, direct liquefaction, indirect liquefaction (Fischer-Tropsch), coal water fuels, combustion, and beneficiation. He has had almost 20 years experience with Gulf Research and Technology, and 13 years with Energy International. Over the past twenty years Mr Davis has had a major role in UCG field test programs in the U.S. and New Zealand, including Rawlins 1981, Rocky Mountain 1, Huntly 5-spot 1993, Hanna III-IV 1977-79, Centralia Partial Seam CRIP 1983-4, Rockdale 1978-80. Mr Davis operates out of Pittsburgh PA and will be visiting CSIRO in 1999.

**Location**

Queensland Centre for Advanced Technologies is a CSIRO research facility for minerals, energy and associated industries, built with support of the Queensland Government. It is located in the western suburbs of Brisbane, about 40 mins from the airport. It is the site of a new coal gasification research facility operated for the Black Coal CRC.

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**CSIRO Workshop**

**UNDERGROUND COAL GASIFICATION**

**ENVIRONMENTALLY FRIENDLY FUELS FROM COAL?**

**23 March 1999**

CSIRO Queensland Centre for Advanced Technologies
2643 Moggill Rd, Pinjarra Hills, Q

A one day workshop with presentations describing the potential and developments of in situ gasification of coal world wide. The implications and commercial opportunities in Australia will be discussed. Burl Davis who has over 20 years experience in underground gasification in the US is the keynote speaker.

**Registration**

To: Sharyn Dawson, CSIRO, QCAT,
PO Box 883, Kenmore Q 4069
Or email s.dawson@dem.csiro.au

Cost $100 One day workshop including lunch and tea breaks

Underground Coal Gasification

Underground coal gasification holds out some tantalising potential benefits. There is an enormous coal resource available, gasification works just as well on coals which are unattractive to mining, it is deep and remote and has less surface impact than mining, it is safer than mining, and a gas energy source has advantages in use and environmental controls.

Gasification can give a range of products and recent experiments have produced up to 70% hydrogen (by volume). Is this an economic method to produce very large quantities of hydrogen and the source for new environmentally friendly hydrogen based energy systems?

Against this there have been problems in implementing commercial in situ gasification in western countries. Are there fundamental problems with the technology, or is it only a matter of bringing the right combination of factors together at the same time?

This workshop will examine the potential for UCG and its relevance to Australia’s large coal deposits.
Managing environmental impacts associated with large underground coal gasification operations.
Conclusions

Prediction of UCG behaviour

Site selection

Potential environmental concerns

Key aspects of UCG

Introduction
Introduction

- Underground coal gasification has been performed at over 50 sites worldwide since the 1930s

- Operations in the former Soviet states dominate in terms of quantities of coal gasified and the range of coal seam characteristics used

- Gasification sites over 600m deep have been used in Western Europe
Site characteristics

Coal seam thickness, m

Depth, m

- Eastern Europe & USSR
- Western Europe, Africa & UK
- USA
- China
- Australia-NZ
The site characteristics have a major impact on potential environmental impacts, however the main areas of concern for large UCG operations are:

- Subsidence
- Groundwater depletion
- Groundwater contamination

Other environmental issues, like waste water handling, can be handled using conventional equipment from existing industries.
Subsidence

- UCG, like any other coal extraction technique, will cause some subsidence.
- The magnitude of this will be determined by the seam thickness, depth, site geotechnical properties, and the UCG design.
- The impact will depend on surface land use.
magnitude of subsidence
operation, but minimises the likely
This minimises the cost of
thick coal seams
experiments took place in shallow,
Much of the Soviet and American

Subsidence - Historical

CSIRO Energy
Hoe Creek #3 Trial (USA, 1979)

- Total of 11m of coal at 39-55m depth
Minimal subsidence detected.

Much more coal extracted than at Hope CK.

Low subsidence UCG technique applied.

Approximately 10m of coal at 130-140m.
Subsidence can be an issue, but can be minimised through careful site selection and UCG design.

Besides environmental impact, it will also have substantial process control ramifications if at excessive levels, so must be addressed during planning.
process
possible impact on the gas utilisation
production pressure declines, with
product gas composition changes and

UCG operation (←Contamination)
ocan lead to high gas losses from the
groundwater (eg. agricultural)
shortages for other users of

Impacts:
Declining hydrostatic head

Reduction in operating pressure

Groundwater sampling from adjacent monitoring well

Source: Blinderman & Fidler, Water in Mining 2003
Specifying the plant design and this may be a limiting factor in plant size will have a large impact when performed on a similar scale.

Methane or Underground Mining utilisation methods (e.g., Coal Bed Methane, or UDM) should be less than for other resource depletion is site dependent but.
- Benzene and other organics have been found in groundwater near two UCG sites in the USA

- Organic contamination is linked to high operating pressures and was avoided in subsequent US trials

- Soviet testing identified elevated salt concentrations around a large UCG site after closure, but these rapidly decreased to background levels
The hydraulic head dropped to essentially zero. Hoe Creek II ran at a 300 kPa operating pressure.
Contamination was noted in 1977, but did not exceed the limits for livestock watering.

The US government committed to cleaning up old DOE sites in 1991.

Clean-up started in 1995 and continued intermittently until 2003.

Contaminant limits were set by Wyoming State as “Not Detectable” due to the lack of a site environmental licence and full background testing prior to the trials.
Later, only air-spararging was used.

Then combined air-spararging and bio-remediation through activated carbon.

Initially, the groundwater was extracted and filtered.
A significant issue for UCG that requires strict operating methodologies and site selection

Impact most readily reduced by avoiding good water aquifers

Modelling of organics very complex and requires detailed assessment of geochemical properties at the site
At specific sites predict the behaviour of the UCG plant. To do this it is necessary to be able to operate within applicable guidelines. Design of the plant, selection of a suitable site, minimizing impact are the most important factors in.
Site selection criteria

- It is possible to set a series of guidelines that simplify decision making when selecting UCG sites.

- Several proposed sets of criteria have been developed in different countries, such as the UK, USA and Australia, all with a bias towards local conditions.
encourage even caving
permeability, preferably structured to
Root thermally stable with minimal

Minimal faulting and no dips/sills

 Seam depth 200-400 m
 Seam dip >20°
 Coal ash <40% (air dried basis)
 Seam thickness >5 m
Our site criteria 2

- Hydraulic head >200 m
- Adjacent aquifers contain poor quality water and are of minimal permeability

Other notes:
- Limited human activities in vicinity
- No waterways overlying the site
- Subsidence must be acceptable at location
- Coal resource size suitable for long term operation
Eliminate unsuitable sites quickly suitable, but use of simple criteria can suitable, but use of simple criteria can to be performed to ensure that the site is comprehensive analysis will still have environmental impacts are acceptable consistent coal removal geological conditions are suitable for resource of suitable size establishing that it is an economic

All sets of criteria are based around.

Site Selection Summary
A comprehensive approach to modelling is required to adequately predict the behaviour of UCG.

This needs to consider not only the gasification process, but also the interactions with the geological and hydrological environment at the site.

A suite of models is required for this, rather than a single model.
The modelling suite is a combination of custom UCG models, specialised ground deformation models and generally available hydrological models.

It has been validated against experimental data and demonstrated to be capable of predicting the environmental impacts of UCG operations at specific sites.

More information on this is contained in a poster and presentation in the main Petrotech2007 conference.
acceptable
the operation will be environmentally
specific site is required to verify that
comprehensive modeling of UCG at a
assist in site selection, however,
Generic criteria can be specified to
the operating conditions.
characteristics, gasifier design and
determined by the combination of site
Environmental impacts are largely

Conclusions

CSIRO

Carbon-energy
Simulating cavity growth, gas production and associated processing for underground coal gasification.
cost alternative for fuel and synthesis gas
in the technology in recent years as a low
capabilities have led to increased interest
sensing, control systems and modelling
improvements in drilling, remote
characteristics used
Gasified and the range of coal seam
dominate in terms of quantities of coal
operations in the former Soviet states
since the 1930s
been performed at over 50 sites worldwide
underground coal gasification (UCG) has
Carbonenergy
Introduction
Key aspects of UCG

Process performance & economic viability

Site selection & characterisation

Groundwater & surface impacts

UCG Design & Behaviour prediction

Social perceptions

Case study analysis
we have taken a comprehensive approach, analysing only a part of the process, but analyses of public perceptions of public perceptions of surface and groundwater impacts of gasification processes of geological factors of a complex system of interacting UCG research involves analyses of a comprehensive model of UCG processes.
Modelling suite for UCG
as a significant installation
synthetic Liquid Fuels was selected
production of 10,000 bbl/day of
A plant size with nominal
UCC plant at any specific site
performance of a commercial scale
operational and environmental
demonstrate the analysis of
case study is required to
Site identification for Case Study

This site is about 300km west of Brisbane, Queensland. Coal outcrops (black) are surface mined, but the high ash content means that underground coal mining is not viable.

10m thick at 390m
3 Modules as arranged in base case

Module design

- 
- 
- 
- Production well
- Vertical well
- Injection well

Coal seam dips at 2°

Direction of flow

North

UCG Design for Case Study
Behaviour prediction

One of the key problems with past UCG operations has been the difficulty in understanding what is happening.

Many months of data analysis and modelling was required to interpret results from some experimental trials.

Modern computing allows the opportunity for real-time assessment of the reactor behaviour, if suitable models can be developed.
Coal model

Gas

Diffusion of gases
IN
OUT
Char

{ Gasification reaction zone

{ Devolatilisation zone

Evaporation front
Heat Transfer
Water Flows and Evaporation
Gas Flow and Reactions
Coal/char Structural Changes
Coal & char Reactions
Temperature
Porosity
Carbon Conv.
Fr. Oxygen
Impact of reactant gas mix and water predictions from the coal model
Predictions from the coal model - Impact of pressure and temperature

Coal face recession rate (mm/hr)

Gas temperature (K)

Pressure (atm)
efficient gasification
operating regimes that are desirable for
Can be used to predict the general
into more complex models
under pseudo-steady state conditions to feed
Makes spot predictions of coal behaviour
cavities
gas flow and heat transfer features of real
relevant to UCG as it neglects many of the
Does not provide standalone predictions
Resizing of the matrix with growth
Rock & coal breakage and collapse
- Radiation
- Convection
- Conduction
Heat transfer
Water flows and evaporation
Gas flow and reactions
Coal/char structural changes
Coal & char reactions

Elements of a cavity model
Predicts accurately:

- Cavity volume changes
- Product gas composition and flow

Hindrances to model performance:

- Requires detailed site information
- It is difficult to accurately predict the shape of complex gasification arrangements
The synthesis plant is very high and the capital cost of the products, but the high value of the consider due to the high value of the synthesis of liquid fuels providing gas for Fischer-Tropsch. This is a tempting process to produce and a low cost option for...
Based on a 10,000 bbl/day plant

CBP = Vertical Wells technology & CRIP = Generic directionally-drilled technology

**Carbon Energy**

**Economics of Liquid Fuel Synthesis** CSIRO
Comments on liquid synthesis

- The gas specification for this process is much more stringent than for electricity generation and it will be difficult to convince financiers that UCG alone can supply a reliable gas feed.

- Large scale UCG with gas blending can maintain constant composition, but may lead to environmental problems.
Specialised geotechnical and hydrological models are required to provide accurate of the physical behaviour at the site, only simplified versions are used in the other models to reduce complexity.

The physical site behaviour is important in ensuring that predictions of operational and environmental performance are accurate.
COSFLOW was developed by CSIRO and NECO in Japan with assistance of JCOAL & NEQDO.

COSFLOW simulates water and gas flow through fractured rock (e.g., permeability and porosity), estimates rock fracture induced changes in hydraulic ocrossent Continuum = efficient simulation of the phase compressible fluid flow of rock mechanics of layered strata with one of two phases coupled with rock flow and gas emission. The mine issues, such as ground deformation, water flow and specific objective of addressing, model developed with a coupled dual porosity two phase flow.
INTERACTION

- Mining induced strata fracture/deformation
- Change in permeability and reservoir pressure
- Caved, fractured and deformed zones
- Ground water flow
- Change in reservoir pressure and relative permeability
- Change in effective stress
- Gas diffusion and flow
- Vertical Displacement
Commonly available packages MODFLOW and MT3D are used to predict larger scale hydrological behaviour around the UCG site.

- MODFLOW simulates three-dimensional groundwater flow through a porous medium by solving the flow equation using the finite difference method.

- MT3D simulates the advection, dispersion and chemical reactions of contaminants in groundwater flow systems in either two or three dimensions.
Salt contamination

In coal seam
Maximum (20 years after operations)
Constant Release - no Reaction or Adsorption

100 years after operation
Springbrook Sandstone

Benzene Contamination

Carbon Energy

CSIRO
Each site is unique, so all modelling must be repeated for the specific size of installation at the actual site.

A general finding is that it appears possible to develop and environmentally sound and operationally efficient plants at suitable sites.
be acceptable environmental performance is likely to verify that the sites and to verify that the performance at specific to test the performance at specific approach. It is necessary to use this approach. A comprehensive suite of models has been developed and demonstrated aspects of UCG based processes has that provides predictions of all.