

Going underground

Michael Green argues that ignoring underground coal gasification is wasting a key clean coal technology

LENIN in 1913 was one of the first to ask why miners were sent underground, when it was known, even in those days, that a useful gas can be produced *in situ*. The process of underground coal gasification, or UCG as it is known, is deceptively simple but it has taken most of the 20th century to produce an effective and controllable process, which can satisfy the environmental and economic technical constraints of a clean coal process. This article will show that UCG is now ready for the commercial challenge of clean coal conversion.

UCG technology

In the basic UCG process, two wells are drilled into the coal, one for injection of the oxidants and the other, some distance away, to bring the product gas to surface. Depending on its age, composition and geological history, coal varies considerably in its flow resistance, so simply relying on the natural permeability of the coal to transport the gas is generally not satisfactory. High pressure break-up of the coal with water (hydrofracturing), electric-linkage and reverse combustion have all been used with varying degrees of success in both pilot and commercial-scale operations in Europe, the US and the former Soviet Union.

In-seam drilling was identified at an early stage as a better way forward, but steerable drilling in coal only started to become available in the latter stages of the US programme of UCG (1975–1990). The breakthrough came when directional in-seam drilling was combined with a system of retractable injection known as controlled retractable injection point (CRIP) as in Figure 1. This arrangement provided both an unobstructed path for the departing gases and a method of controlling the reactions between oxidant and coal.

The new system was first tested in shallow coal at the Rocky Mountain trial in Wyoming, US, where over 14,000 t of coal was gasified. The technology was further developed in deeper coal at the European UCG trials in Belgium

(860 m depth) and Spain (550 m depth). The latter trial, which took place between 1993 and 1998, was able to take advantage of developments in drilling, injection and completion equipment in the oil and gas industry. Since these trials, further improvements in the sensing of coal boundaries from downhole drilling assemblies, telemetry to surface and active devices to control the intersection of wells within the coal seam have been made.

The underground completion of the injection and production wells and the control of the gasification process using moveable injection has been tested and proven in the European trials. The Soviets showed in the 1960s that large-scale UCG operation (up to 1200 MWT) could be achieved with vertical well configurations by the use of simultaneous gasification in multi-well configurations. These same methods of scale-up, already proven in vertical wells, now have to be applied to commercial-sized panels of directionally-drilled wells.

sites for UCG

Coal seams are porous strata that are normally connected to aquifers and are maintained at hydrostatic pressure, which increases with depth. The gas reaches the surface at coal seam pressure, typically 60–100 bar, which gives it significant potential energy in addition to the chemical energy in the combustible gases. UCG in a deep coal seam provides greater protection from the spread of pollutants and this is further minimised by an operating regime which maintains an inward flow of liquids and gases towards the reactor at all stages of the process, from start-up to final shut-down and stabilisation of the abandoned cavity.

Site selection is the key to a successful UCG project. The characteristics of the coal seam, the permeability and fault structure of the local strata and the geology and hydrogeology of the area which surrounds the target coal seam must be fully understood. This requires the drilling of pilot bore holes to coal seam depth and for coring and seam characterisation, and a good quality seismic survey (preferably 3D) of the whole area. Modelling of the hydrogeology will be required to meet European ground water requirements. This detailed

exploration work is one of the major upfront costs of UCG (the same is true for conventional mining), and carries the risk that the first target site could be rejected on environmental or other grounds and another has to be found.

UCG and surface gasification can use air or oxygen as the injected oxidant. The former Soviet schemes used mainly air in shallow seams, to produce a low calorific value gas suitable for the co-firing of thermal power plant. Specially-adapted gas turbines have since been developed to operate on low CV gas. In deeper seams, the compression costs of air versus oxygen are increased and a product gas containing large quantities of nitrogen requires larger plant for processing and acid gas removal. There is also evidence that enriched air or oxygen enhances cavity growth. In spite of the high cost of cryogenic air separation for oxygen production, oxygen firing for UCG is favoured in deep seams. New lower-cost methods of air separation using membranes are becoming available, which could lower the capital costs and energy overhead associated with cryogenic separation units.

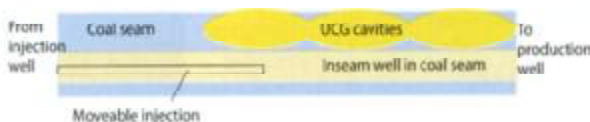
economics

Various estimates have been made of the costs of UCG. A scoping exercise by the UK Department of Trade and Industry (DTI; *Review of the feasibility of underground coal gasification in the UK*, DTI/Pub URN 04/643, October, 2004) suggested that the cost of generating electricity with UCG product gas would be about 2 p/kWh for a 300 MW power output project. In the same reference, the costs of electricity from coal-based IGCC are higher, at 2.2–3 p/kWh.

An estimate of the cost of clean UCG gas, for both offshore and onshore gas, is shown in Figure 2. This calculation suggests that an onshore UCG production station complete with gas cleaning would produce clean gas at around £1.4/GJ. The UK studies have focussed recently on the large coal resources that lie under estuaries and the sea close to shore. It is estimated that costs rise to £1.8/GJ for a near-shore UCG scheme. These figures compare with average 2004 purchase prices by power generators, as listed by the DTI, of £2.1/GJ for natural gas and £1.2/GJ for mined coal. This preliminary estimate indicates that the cost of UCG



Figure 1: Principle of moveable injection for coal seam gasification



gas is highly competitive with current natural gas prices at outputs greater than 200 MWt. A breakdown of average UK prices can be found at http://www.dti.gov.uk/energy/inform/energy_prices/tables.

Feasibility studies of UCG are underway or being planned in most countries with large coal resources. The UK has just concluded an extensive review (1999–2004) of the potential for UCG as a method of exploiting its large coal resources on land and offshore and a feasibility study of UCG under the Firth of Forth is underway with industrial support. Many other countries with large coal resources have a renewed interest in UCG. China has a number of trials in progress and others are in various stages of planning in Australia, South Africa, UK and the US.

comparison with other clean coal processes

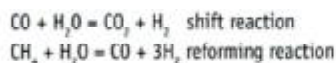
The UCG gas which reaches the product wellhead contains the combustible gases hydrogen, carbon monoxide and methane, plus some higher hydrocarbons. In addition, water vapour, nitrogen, acid gases, intermediate gasification products like phenols and benzene and small quantities of ammonia, particulates and heavy metals are present and generally have to be removed. Most of the ash, char and some of the sulphur is left underground in the abandoned cavity.

The gases from the process, after dewatering, particulate removal and acid gas separation, are suitable for combined cycle power generation, which is more efficient than thermal (ie steam-raising) plant. The DTI publication referenced above compares UCG with other forms of fossil-fuelled power generation and shows that the emissions in tonnes of CO₂/MWh of electricity generated are comparable with coal-based IGCC, and significantly lower than modern thermal plant. Only natural gas and renewable energy can achieve lower equivalent emissions than UCG or IGCC.

Coal will continue to be an important and probably the largest energy source in most developed and emerging countries. Efficiency improvements alone, setting aside the difficulties of implementation, are unlikely to slow the increase in world greenhouse gas emissions. If the emission reductions sought by governments, and world climate agreements are to be met, more dramatic technical solutions are required. Most reviews are pointing to CO₂ capture and storage (CCS) as the most promising technology for fossil fuel emissions.

UCG has some interesting synergies which may be important to CCS. First and

foremost it is a gasification technology with all the benefits that accrue in terms of CO₂ capture from pre-combustion gas. These include a smaller, more efficient separation plant, lower capture costs, and the ability to produce hydrogen in bulk quantities. Furthermore, the composition of UCG clean gas, as outlined above, and the high pressure available, suggests that a range of CO₂ capture options could be considered. One is simply to capture CO₂ in the pre-combustion stream and lower the final CO₂ emission from 0.80 to 0.55 t/MWh of electricity generated. More CO₂ can be captured by applying the shift and steam reforming based on the following reactions:



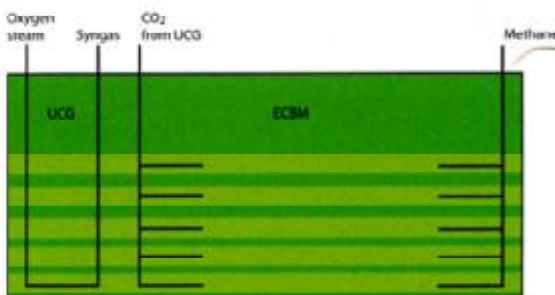
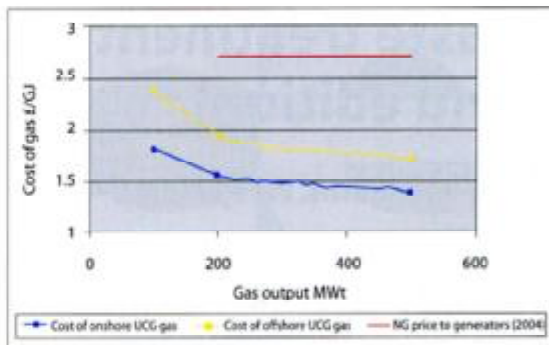
The scope for optimising the capture process is large, and emissions already low for coal can be reduced to those of natural gas combined cycle (CCGT) or taken to a level approaching renewable energy. The process is particularly well suited to the production of low-carbon gas mixtures of hydrogen and methane. These have higher energy densities and are safer to handle than pure hydrogen. Such mixtures may be suitable for existing gas transmission lines and could make an effective transport fuel for some vehicles.

close-coupled UCG with CO₂ storage

The coal seam in the vicinity of the UCG gasification seam is a potential storage area for CO₂ which can have several advantages. It can be accessed with the same drilling equipment as UCG and the pipeline distances are short. In addition, the gas may not need to be purified to the same extent as a CO₂ gas-gathering pipeline to a depleted gas well or other distant CO₂ storage location.

CO₂ injection into coal seams displaces methane and itself is adsorbed onto the coal in a physical bond. The use of CO₂ to sweep the methane out of the coal is a process known as enhanced coal bed methane (ECBM), which offers considerable potential both as a method of extracting more methane from the coal and as a permanent store for the CO₂. ECBM has so far been tested in China, Japan, the US and Poland, and by and large, the results have been encouraging, in spite of potential permeability and coal swelling problems in some cases.

The concept of combining UCG and ECBM (see Figure 3) suggests a neat method of close-coupled UCG-CCS. The same plant would service both operations: the CO₂ could be captured



from the UCG process and any methane produced could be used to enhance the calorific value of the product gas. One possible problem is that the quantity of coal required for CO₂ storage per unit of energy produced is much larger than the amount of coal consumed for UCG. Multi-seam configurations for the CO₂ storage would improve the volume of CO₂ stored. The combination might be well suited to a CBM field that is reaching the end of its production life.

conclusions

UCG, based on advanced drilling and completion technology developed in the oil and gas industry, offers a modern method of coal exploitation that is safe, environmentally benign and potentially low cost. The product is a syngas, which on processing can be used directly for industrial heating, chemical manufacture such as high quality diesel, or for power generation using high efficiency combined cycles.

The technology has been proven in three pilot-scale demonstrations and is ready for commercialisation. Most countries with large coal resources are examining the potential of UCG and several demonstrations are planned or underway in the US, Australia and China. Initial studies suggest that economics of UCG as a method of gas production for power generation compare well with current world gas prices.

UCG offers considerable flexibility for the capture of CO₂ in the product gas stream and the high pressure of deep coal seams is likely to reduce the size and cost of capture plant. The possibility of close-coupled UCG with ECBM looks particularly promising. **tce**

(Top) Figure 2: Comparison of estimated UCG gas price for onshore and offshore generation with 2004 natural gas price
(Below) Figure 3: Close-coupled UCG and ECBM

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