

Site Selection – A key to Underground Coal Gasification (UCG)

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Abstract:

UCG is a very site specific technology. It cannot be used to extract all the unmineable coal that is available. The stringent conditions with rigid technical and environmental requirements, constrain all the available coal and lignite reserves from being amenable to UCG. As a result, site selection forms the most critical part of any UCG Project. It requires proper understanding and knowledge of geology, tectonics, hydrogeology etc. of the area.

UCG has an intrinsic environmental risk in the form of ground-water contamination. The spatial distribution of coal/ lignite, its thickness, number of seams, its relationship with the surrounding rock strata (tectonic disturbance, petro-physical & geo-mechanical properties) and hydrogeology of the system play an important role in determining the suitability of a site for UCG.

The paper deals with the considerations that should be given to the nature of a potential UCG project site during the site selection process. These considerations will allow the environmental aspects associated with the project to be managed most effectively. They include the nature of the coal seam characteristics; the nature of the site in terms of the risks posed to groundwater; and the nature of the adjacent land use and associated planning. The paper also covers ONGC's experience in selecting sites for UCG through various stages of exploration.

Introduction

The search for unconventional sources of hydrocarbon such as Coal Bed methane, Underground Coal Gasification, Shale Gas, Gas Hydrate etc become utmost important to meet the future crunch of our conventional energy resources. The unconventional sources will play a major role in reducing this gap in demand-supply.

Coal is the most abundant and important fossil fuel of India and accounts for 70% of India's energy need. India has the 4th largest coal reserves in the world with estimated reserves of 267.08 billion tones as on 1st April'2009 ("Coal Resources of India," Coal Wing, GSI, Kolkata, 2009), and ranks 3rd in coal production. But, the total recoverable reserves of coal are only about 15.8 % (41.87 billion tones) (based on CMPDI formula, Chaudhuri, 2006) leaving a large quantity (~225.22 billion tones) of un-mineable coal reserve.

UCG is one of the feasible technologies to harness energy from deep un-mineable coal seams, in an economically and environmentally clean way.

Underground Coal Gasification (UCG)

UCG is a process to convert the unmineable coal / lignite into combustible gases by gasifying the coal/lignite in-situ. The coal reacts with injected air/oxygen and steam to form gases, liquids and ash. Produced gases are mixture of combustible (carbon monoxide, hydrogen & methane) and non-combustible gases (carbon dioxide, nitrogen & un-reacted water vapor).

The main advantages of UCG is that it facilitates exploitation of deep coal reserves that cannot be mined, no solid wastes on the surface and reduced emission of green house gases by CO₂ sequestration. The UCG syngas historically was used as fuel gas / town gas in Former Russian states and China. But recent research and development in technology has shown that it can be used for ammonia / fertilizer production, power generation or synthetic transportation fuel. In the ultimate clean coal form, syngas, will lead to efficient capture of CO₂ and prove to be an enabler for the eventual shift to Hydrogen, the most promising energy carrier of the future.

Site Selection

There are three key elements to selecting a site that is environmentally suitable for UCG development:

- selecting suitable coal seam characteristics that will provide environmentally advantageous operational conditions;
- selecting a site where the geological and hydro-geological characteristics mean that the risk of groundwater pollution from the UCG operation is negligible; and
- choosing a suitable surface location that satisfies the various planning requirements that may apply to the operation.

The factors that have to be considered in relation to these aspects and the site investigation methods that has to be adopted in order to select a site that satisfies these criteria are

1. Coal seam characteristics:

The coal seam characteristics to be considered at the site selection stage are:

- depth;
- seam thickness;
- coal rank;
- seam dip;
- degree of disturbance;
- nature of adjacent strata and
- porosity and permeability

Seam Depth: The main influences of increased depth on UCG performance are improved process control, increased gasification pressure and decreased permeability of coal and adjacent strata. However, a balance has to be drawn between the improved performance and the increased cost with increasing depth.

Seam thickness: The coal seam thickness is also important as seams thickness more than 2 m permit a greater area of coal to be gasified from a single pair of wells providing both economic and environmental advantages whereas if the seams is less than 2 m it may lead to heat losses and thus leading to low thermal efficiency and lower quality product gas.

Seam dip: Shallow dipping seams are preferable as tars and fluids flow away from the gasification zone. Such seams facilitate drainage and the maintenance of hydrostatic balance within the gasifier.

Rank of Coal: Four characteristics of coal are fundamental to the gasification process i.e. chemical reactivity; chemical analysis; swelling characteristics; and thermal decomposition characteristics (volatiles content). The low rank coals are easier to gasify in-situ as the lower rank coals tend to shrink upon heating, enhancing permeability and connectivity between injection and production wells. Hence, low rank, high volatile, non caking bituminous coals are preferable for UCG. However, UCG has been successfully carried out in higher rank coals.

Structure and tectonic disturbance: The major faulting or small fracture sets create conduits from the underground gasification zone to surrounding strata or to the surface. These could potentially provide a pathway for water inflow, gas migration or contaminant transport. The fault with throw more than seam thickness will be hindrance to the fire front movement during gasification. Hence, the areas that are free of

major faulting in the vicinity (at least 50 m of the proposed gasifier) should be preferentially targeted for UCG.

Nature of adjacent strata: In some cases the immediate roof strata to the seam (defined as 5 times the seam height) cave readily due to poor geo-mechanical properties and if an aquifer is present in the near vicinity of the seam, it will get connected to the gasifier. Hence, seams where there are no overlying aquifers within a distance (vertical separation) of 100 meters are preferable.

2. Geological and hydro-geological characteristics:

The potential impacts to groundwater forms one of the most technically challenging aspects of the site selection evaluation process. The main regulatory concern in terms of groundwater is the fact that substances produced by the reactor will almost certainly enter 'groundwater' in the immediate vicinity of the reactor.

The risks to groundwater from the gasification reactor itself at any given site depend on whether the sub-surface characteristics of that site allow conditions to develop that will allow contaminants to be transported beyond the 'Permanently Unsuitable' (PU) zone in significant quantities or concentrations. The PU zone is essentially defined as a block of strata where the water quality and/or yield are so poor that groundwater in that area cannot realistically be regarded as an environmentally or economically significant 'aquifer'.

Potential contaminants fall into four main categories:

- product gases during gasification;
- pyrolysis products (both aqueous and gaseous phase) during gasification, usually caused when product gases are 'pushed' through the pyrolysis zone;
- gases with potentially high contaminant loads during shutdown (usually caused by pressure build up if the reactor is not properly vented); and
- leaching and transport of aqueous phase contaminants post gasification (either from the reactor or from sections of strata that have received gas escapes during operations and therefore contain dissolved contaminants).

The risk of groundwater pollution being caused by these contaminants depends on natural site characteristics and factors such as gasification pressures and borehole design. The evaluation of the risk to groundwater posed by any particular site must take into account all factors relating to contaminant production, contaminant transport and assessment of migration pathways based on geological and hydrogeological evaluation.

The potential contaminant migration pathways that present a risk of gas escapes or aqueous transport beyond the PU zone are:

- Joints, cleats and slips
- Permeable rock matrices
- Joints, fissures, fractures and bed separation
- Faulting
- Igneous dykes and sills
- Karst/solution features
- Mining/caving induced features
- Abandoned boreholes

The establishment and definition of the 'Permanently Unsuitable' (PU) zone of groundwater around the coal seam is very important to the assessment of risk. The first stage of the risk assessment process is to carry out initial assessment of local aquifers and estimate the extent of the 'Permanently Unsuitable' groundwater zone.

The second stage of the risk assessment process is to determine if any of the potential transmission pathways discussed previously exist at the site and can provide realistic gas or leachate contaminant transport pathways. Once these are identified, an iterative process of geological and hydrogeological assessment should be carried out to determine whether these pathways are likely to promote transport of contaminants to locally significant aquifers (beyond the 'PU' zone).

In simple terms, the evaluation of geological and hydrogeological characteristics requires analysis of two main driving factors. One, identifying the main potentially transmissive features and whether they could link up to provide a continuous transmission pathway beyond the permanently unsuitable zone; and two, determining whether hydrogeological conditions are likely to promote transmission of contaminants through potentially transmissive features.

3. Land use planning

In terms of land use planning, it is prudent to ensure that the development of UCG resources can take place in accordance with the full and proper protection of the environment and the local community. It would be appropriate to assess the sensitivity of the receiving environment and the magnitude of the potential impact in order to arrive at a robust score for suitability of a location in terms of topography (landscape), forest cover, its ecology, surface water and groundwater, land quality, cultural heritage, road network, socio-economics system and pollution.

Site Selection Procedures:

Assessment for site selection is based on the geology and hydrogeology of the site and requires appropriate studies by compilation and analysis of historical data (site investigation data from previous coal prospect investigations) and detailed field investigation methods. Site selection will usually involve studies of earlier data as the main aim of suitability of sites. If a need for additional data is felt, then the detailed field investigation is carried out. This is undertaken only after sufficient information is available that the site does not pose a risk to UCG.

1. Compilation and analysis of site investigation data from previous coal prospect investigations

Study of existing data is an important analysis at the site selection stage. It should provide all of the necessary information and should be used to carry out a 'first' pass assessment of the conceptual hydrogeology and risk at the site that can be used to determine what physical site investigation methods need to be employed.

Analysis of previous coal prospect investigations or other deep site investigation data is very important in locating faults and determining the lateral extent and nature of coal / lignite deposit. Lateral continuity of coal / lignite deposits is likely to be limited in a sedimentary environment, except where there has been significant faulting or intrusions. Conclusions relating to lateral continuity should be supported by drilling data of boreholes and detailed Seismic data. This should also be complemented by analysis of in-situ hydrogeological data from the previous coal prospect investigations.

2. Field investigation techniques

Site investigations are likely to be partly opportunistic and partly based on the study of existing data. This may include both drilling of boreholes and geophysical investigations and should be integrated with the geological and hydrogeological investigations.

Where there is little data available, further seismic exploration will be required. This data can be used to confirm lateral continuity and thickness of strata layers. The core samples of coal and adjacent strata need to be analysed for geochemical, geo-mechanical and petro-physical properties. This will help in predicting the quality of the Syngas and the subsidence due to UCG operations.

Two bore holes should be predrilled in smaller diameters for the geological and hydro geological investigations. In addition a third hole will be drilled to provide monitoring of the aquifer. These three bore holes should form the basis of the hydro-geological investigations. In each borehole the three parameters that need to be measured are the water pressure, transmissivity and water quality. The vertical profile for each of these three parameters alongside the geological profile, represent the key parameters from which the components of the hydrogeological model can be established.

ONGC's experience:

ONGC has revived its UCG project in 2004 and fifteen sites were studied for their suitability out of which five sites have been found suitable. The project has provided first hand opportunity in evolving a site selection methodology by analysis of previous coal prospect investigations and generation of additional exploration data.

1. Compilation and analysis of existing data

As part of the site selection process, ONGC along with the partnering companies gathered all available data of the previous coal prospect investigations. This included information on the topographic survey, geology, borehole litho-logs, electro-logs, seismic survey, geochemical, geomechanical and petrophysical properties of the samples of coal and adjacent strata. This data was used in the preparation of geological and hydrogeological model of the site and estimation of coal / lignite reserves. This provided a first assessment of hydrogeology and risk at the site. This information was used in identification of additional field investigations that were required for finding out suitability of the site.

2. Field investigation

As a consequence of analysis of previous coal prospect investigations, additional exploration data was acquired wherever it was deemed necessary. This included

- Drilling of additional boreholes
- Electro-logging viz. density, gamma ray, resistivity, sonic, etc in selected boreholes for correlation.
- Seismic survey (High resolution seismic survey) for precise mapping of the faults and continuity of coal / lignite.
- Proximate, ultimate and maceral analysis of the coal / lignite on core samples.
- Geo-mechanical analysis viz. tensile strength, compressive strength, grain density, young modulus, poisson ratio and petro-physical analysis i.e. porosity & permeability of coal/lignite and adjacent strata.
- Estimation of hydro-dynamic parameters i.e. filtration factor, transmissibility, conductivity of the aquifers above and below the coal/ lignite seams.
- Determination of chemical composition of ground water to find out whether it is within the maximum permissible limits of concentration of pollutants in drinking water and technical waters.

Geological and hydrogeological model which was prepared based on the analysis of previous coal prospect investigations was updated in light of additional exploration data for finding out suitability of the site.

Conclusion

- UCG is the only feasible technology to harness energy from deep unmineable coal seams, in an economically and environmentally clean way. The product gas from UCG can be used to generate power, fertilizer, ammonia, and methanol and can be converted into clean synthetic liquid fuels.
- The three key elements to selecting a site that is suitable for UCG development are suitable coal seam characteristics; negligible groundwater pollution risk and suitable surface location that satisfies the various planning requirements.
- The potential impacts to groundwater forms one of the most technically challenging aspects of the site selection evaluation process. The evaluation of the risk to groundwater posed by any particular site must take into account all factors relating to contaminant production, contaminant transport and assessment of migration pathways based on geological and hydrogeological evaluation.
- The evaluation of geological and hydrogeological characteristics requires to look for geological structures that can lead to contaminant transport (and potential continuity between these pathways) and buoyancy/pressure or hydrogeological conditions that may promote migration through these pathways to overlying aquifers.
- Assessment for site selection is based mainly on geology and hydrogeology of the site and will require appropriate studies of existing data of previous coal prospect investigations and subsequently additional field investigation.

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