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Resources and economic analyses of underground coal gasification in India

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HIGHLIGHTS

- The potential UCG coal resources in India are 120.666 billion tonnes.
- The potential UCG lignite resources in India are 20.980 billion tonnes.
- The UCG plant is analyzed by considering vertical wells UCG module.
- An equilibrium model and an economic model are combined for UCG plant analysis.
- Capital cost and operating costs are estimated for 100 MW UCG power plant.

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ABSTRACT

India has 298.914 billion tonnes of coal resources and 43.215 billion tonnes of lignite resources. Underground Coal Gasification (UCG) can be used to extract the deep and un-minable coal and lignite resources in India. Total 120.666 billion tonnes coal resource and 20.98 billion tonnes lignite resource are confined to the depth greater than 300 m which would be the potential resources for UCG. A simple approach has been developed for economic evaluation of UCG project. The UCG module can be considered to consist of two vertical wells. An equilibrium model based on elemental composition of coal is used to predict the gas quality and yield. Based on a single UCG module dimensions, syngas production and power generation per module are calculated. The capital and operating costs are estimated for 100 MW UCG power plant with the multiple UCG modules. Three Indian coal samples- one sub-bituminous coal (C) and two lignites (A and B) are used to estimate the capital and operating costs of 100 MW UCG power plant. The capital costs are in the range of $210–246 millions. The estimated costs of clean syngas production per GJ are $1.34, $0.90 and $1.73 for sample A, B and C respectively. The estimated electricity generation costs per MWh using UCG syngas are $24.27, $19.10 and $28.11 for sample A, B and C respectively.

1. Introduction

Energy is the prime driving force for the economic growth of the country. The Expert Committee on Integrated Energy Policy in its Report (IEPR 2006) has estimated that by 2032, primary commercial energy requirement in India would need to go up by 4–5 times, electricity generation installed capacity by 6–7 times and oil requirement by 3–6 times the current level [1]. To meet the estimated energy demand, an efficient and clean use of the available coal and lignite resources is required. The Underground Coal Gasification (UCG) offers a clean source of energy by converting coal/lignite *in-situ* into syngas that can be used either as a fuel or as a chemical feedstock [2]. The UCG has the potential to utilize coal and lignite resources which are inaccessible due to depth and are uneconomical to extract using the conventional mining methods [3]. The Former Soviet Union (FSU) was the first to begin large-scale UCG pilot testing and commercial program in1930s. One of the UCG plant in Angren is operating for the last 50 years. The USA conducted 33 UCG trials in 1970s. After FSU and USA, UCG trials have been conducted in South Africa, China, Australia, Canada, New Zealand, Pakistan, and Europe during 1980–2010 [4]. In India, Oil and Natural Gas Corporation Ltd. (ONGC) has been planning for a UCG trial. The previous feasibility study shows that Indian coals which are at the greater depths are suitable for the UCG [2].

Many UCG projects are in the planning phase while a few are in the pilot phase. During planning phase of the UCG project, a quick estimation of gas produced in the UCG process is necessary for the project viability, using preliminary economic analysis. Several theoretical UCG models have developed for the prediction of UCG

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process performance in terms of gas composition and gas heating value [5–11]. The UCG models have also developed for prediction of UCG cavity growth during the gasification process [3,12–14]. The UCG models have developed based on two approaches, namely, free channel model and packed bed model [8]. These models involve various assumptions to simplify the complex UCG process. After simplification, the model calculations are time intensive and needs detailed information on coal properties, heat and mass transfer rates and kinetic parameters. In the absence of the detailed information, the thermodynamic equilibrium model is the best option for the prediction of gas composition and heating value since it requires only coal composition, reactant ratios, pressure and temperature [15]. The inputs required for the equilibrium model are elemental composition of coal, amount of coal and air and/or steam, temperature and pressure.

In the analysis of UCG project viability, available coal/lignite resource, gas composition, gas yield per tonne, gas heating value and coal consumption rate are the important parameters. In this paper, resource analysis of coal and lignite in India is carried out based on the coal seam depth. For preliminary economic evaluation of UCG project, use of the equilibrium model combined with the simple economic model is proposed. Costs of syngas production and electricity generation are estimated based on capital and working costs available in the literature. Three different Indian coal samples - one sub-bituminous coal (C) and two lignites (A and B) are considered in these analyses.

2. Coal and lignite resources in India

2.1. Coal resources

Total geological resources of coal in India are 298.914 billion tonnes. The depth-wise distribution of the total resources indicate that the Indian coalfields (excluding Jharia) hold 175.609 billion tonnes up to 300 m depth from surface and 86.974 billion tonnes between 300 m and 600 m depth levels (Table 1) [16]. Jharia coalfield, in addition, contains 14.212 billion tonnes up to 600 m depth. The total coal resources between 600 m and 1200 m depth levels stand at 22.118 billion tonnes.

State-wise distribution of Indian coal shows that Jharkhand is at first place in the list with 80.701 billion tonnes followed successively by Orissa (73.710 billion tonnes), Chhattisgarh (52.169 billion tonnes), West Bengal (31.283 billion tonnes), Madhya Pradesh (25.061 billion tonnes), Andhra Pradesh (22.206 billion tonnes) and Maharashtra (10.964 billion tonnes) [17]. These seven states contribute to 99.06% of total coal resource of India.

2.2. Lignite resources

The total geological resources of lignite in India stand at 43.215 billion tonnes. Of these, 6.180 billion tonnes are classified as 'Proved', 26.282 billion tonnes are classified as 'Indicated' and 10.752 billion tonnes are classified as 'Inferred' resources [18].

Table 1
Depth wise coal resource of India (billion tonnes) (01.04.2013) [16].

Depth	Proved	Indicated	Inferred	Total	% Total
0–300	95.092	69.936	10.580	175.609	58.75
0–600[a]	13.760	0.451	0	14.212	4.75
300–600	12.045	58.544	16.384	86.974	29.10
600–1200	2.283	13.699	6.135	22.118	7.40
Total	123.181	142.631	33.100	298.914	100.0

[a] Only for Jharia coalfield for which break-up is not available.

Considering the available depth-wise distribution of total lignite resources (Table 2), 5.705 billion tonnes of resources of Tamilnadu lignite fields occur within 150 m depth. Bulk of the lignite resources of Rajasthan (1.899 billion tonnes), Gujarat (0.707 billion tonnes) and Pondicherry (0.416 billion tonnes) are found to occur within 150 m depths. Thus, a total of 8.768 billion tonnes (20% of the total) of country's lignite resources are confined within 150 m depth from the surface. Further 13.461 billion tonnes (31% of total) of the lignite resources occur between 150–300 m and 20.986 billion tonnes (49% of total) below 300 m depth. In addition to these, about 60 billion tonnes of lignite may likely to be contained within 800–1400 m depth in Kalol basin (Mehsana area), Gujarat.

3. Possible UCG reserves and resources in India

3.1. Coal

In India, total 120.666 billion tonnes coal is at a depth greater than 300 m in which proven coal reserves are 27.647 billion tonnes. Table 3 gives available total coal (resources) and proven coal (reserves) in the seven states of India at a depth range 300–1200 m. If coal at a depth greater than 300 m is considered suitable for UCG, these are potential candidate for UCG extraction.

3.2. Lignite

The depth wise lignite distribution shows 49% lignite occurs at a depth greater than 300 m. If the same depth criterion is applied for lignite as that of coal (i.e. lignite at a depth greater than 300 m is suitable for the UCG), then about 20.986 billion tonnes lignite is available for UCG extraction in the two states of India (Table 3). About 60 billion tonnes of lignite may likely to be contained within 800–1400 m depth in Kalol basin (Mehsana area), Gujarat which would be the potential UCG resource in the future once the technology is proven at the shallow depths.

The suitability of these vast coal and lignite resources may be studied by following approach. The technical process parameters such as gas composition, gas heating value and gas yield per tonne of coal are predicted using the thermodynamic equilibrium model. The inputs to the model are available information on depth, thickness and elemental composition of coal. The technical process parameters from the equilibrium model are combined with the simple economic model (economic model does not consider the time value of money, taxes and rate of return) gives the costs of clean syngas production and electricity generation based on the capital and working costs.

4. UCG module design

The design of UCG module is an important task since it affects project viability. In the simplest form, UCG module consists of

Table 2
Depth wise lignite resource in major lignite rich states [18].

	State	Geological resources of lignite (billion tonnes)			
		0–150 m	150–300 m	>300 m	Total
1	Tamilnadu	5.705	8.433	20.208	34.347
2	Rajasthan	1.899	3.012	0.777	5.689
3	Gujarat	0.707	2.014	0	2.722
4	Pondicherry	0.416	0	0	0.416
5	Kerala	0.027	0	0	0.027
6	J&K	0.009			0.009
7	West Bengal	0.001	0.001	0	0.002
	Total	8768.14	13.461	20.986	43.215

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