Underground coal gasification: A new clean coal utilization technique for India

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Abstract

Energy demand of India is continuously increasing. Coal is the major fossil fuel in India and continues to play a pivotal role in the energy sector. India has relatively large reserves of coal (253 billion tonnes) compared to crude oil (728 million tonnes) and natural gas (686 billion cubic meters). Coal meets about 60% of the commercial energy needs and about 70% of the electricity produced in India comes from coal, and therefore there is a need for technologies for utilization of coals efficiently and cleanly. UCG offers many advantages over the conventional mining and gasification process. UCG is a well proven technology. Due to the site-specific nature of the process, possibility of land subsidence and surrounding aquifer water contamination, this technology is still in a developing stage in India. Potential for UCG in India is studied by comparing the properties of Indian coals with the properties of coal that are utilized by various UCG trials. The essential issues are elaborated for starting UCG in India based on the reported information from the successful field trials conducted all over the world. Indian industries are in the process of initiating pilot studies of UCG at various sites. This study will help to motivate both applied and theoretical research work on UCG sites in India and after detailed analysis it will provide basic data to interested industries.

Keywords: Indian coals; UCG; Modeling; Feasibility

1. Introduction

Coal is the major fossil fuel in India and continues to play a pivotal role in the energy sector. Coal meets about 60% of the commercial energy needs and about 70% of the electricity produced in India comes from coal [1]. Hence, there is a need for technologies for utilization of coal efficiently and cleanly. Depleting oil and gas reserves can be substituted with abundantly available coal thus prolonging the reserves of all the fossil fuels for use by the future generations. Due to the availability of low price crude oil and natural gas, the coal consumption and process development was slow in the last few decades. But as the oil and natural gas reserves deplete, coal will again emerge as the best option for energy production.

Coal usage has been affected by the pollution caused by its transport, storage, and combustion [2]. To deal with these problems, "clean coal technologies" have been adopted worldwide [3] such as integrated gasification and combined cycle (IGCC), the pressurized bed combustor (PBC) combined cycle, British coal topping cycle in UK [4], low emission boiler system (LEBS) and high performance power system by the US Department of Energy [2].

Underground coal gasification is a promising technology as it is a combination of mining, exploitation and gasification. The main motivation for moving toward UCG as the future coal utilizing technique is the environmental and other advantages over the conventional mining process. Some of these benefits include increased worker safety, no surface disposal of ash and coal tailings, low dust and noise pollution, low water consumption, larger coal resource exploitation and low methane emission to atmosphere [5–9]. UCG is particularly advantageous for deep coal deposits and steeply dipping coal seams since at these conditions less gas leakages to the surroundings and high pressures favor methane formation. But UCG involves some environmental impacts such as land subsidence and ground water reserve pollution, which serve as disadvantages. Thus before the UCG site is selected there is a need for a thorough environmental impact assessment and complete risk analysis.

UCG is relatively well developed in countries like the USA, Russia, France, Spain and China [10]. They have performed a number of field trials and are ready to commercialize UCG technology. With a vast proven reserve of coal, India has the potential to use UCG technology to utilize coal effectively. The possibility of initiating UCG projects in West Bengal and Rajasthan have been indicated by companies such as the Oil and Natural Gas Corporation Ltd. (ONGC) and the Gas Authority of Indian Ltd. (GAIL), on a pilot basis [11,12]. ONGC have signed a Memorandum of Understanding (MoU) with the Skochinsky Institute of Mining (SIM) of Russia and Coal India Limited (CIL) for an UCG pilot study [11]. These pilot projects are being carried out as per the recommendations of the consultant from the SIM of Russia [12]. The UCG site will be selected based on the suitability on various considerations including coal quality, area and environmental aspects. ONGC, Gujarat Mineral Development Corporation Ltd. (GMDC) [13], Gujarat Industries Power Company Ltd. (GIPCL) and Neyveli Lignite Corporation Ltd. (NLC) have also entered into an MoU for studies in UCG [13].

GAIL (India) is planning to use lignite, which cannot be mined commercially, to produce synthetic gas by employing underground coal gasification technology in Rajasthan. GAIL plans to use the gas so produced to generate 70–80 MW of power. It may tie up with Ergo Exergy Technologies Inc., Canada, for sourcing "in situ lignite gasification" technology for its proposed project [14]. Reliance is also interested to set up a pilot UCG plant. Essar want to use the product gas for their proposed steel plant in Orissa [15].

The objective of this article is to analyze the feasibility of UCG for application to various Indian coal mines based on quantitative information available in open literature.

2. Indian coals

2.1. Indian coal reserves

The study of reserves and availability of Indian coal have indicated that a major chunk of the reserve consists of weakly to non-coking variety of bituminous, sub-bituminous and lignite coal which are distributed all over India, located at different depths. Coal which when heated in the absence of air forms coherent beads, free from volatiles, with a strong and porous mass called coke, is called coking coal. Coals which do not have coking properties, are non-coking coals. Indian coal is mostly non-coking coal. A large quantity of such non-coking coal is available in India.

India has a total of 253 billion tonnes of coal reserves [16]. However, only the states of Bihar and West Bengal have mineable coal. Table 1 shows the current coal reserves in India. The statewise coal reserves are tabulated in Table 2.

Table 1
Coal reserves in India on 01.01.06 [16]

Coal	Total reserve (billion tonnes)	Proved reserve (billion tonnes)	Indicated reserve (billion tonnes)	Inferred reserve (billion tonnes)
Coking	32	17	13	2
Non-coking	221	79	106	36
Total	253	96	119	38

Table 2
Statewise coal reserves in India on 01.01.06 [16]

No.	State	Quantity of coal (billion tonnes)
1	Andhra Pradesh	17.145
2	Arunachal Pradesh	0.090
3	Assam	0.376
4	Bihar	0.160
5	Chhattisgarh	41.442
6	Jharkhand	73.898
7	Madhya Pradesh	19.758
8	Maharashtra	9.077
9	Meghalaya	0.459
10	Nagaland	0.020
11	Orissa	61.999
12	Uttar Pradesh	1.062
13	West Bengal	27.815
	Total	253.301

2.1.1. Lignite

Lignite, the 'brown coal', is a potential solid fuel resource available in India. Its quantity is limited as compared to coal. It is distributed in the states of Tamil Nadu, Pondicherry, Gujarat, Rajasthan and Kashmir valley of Jammu and Kashmir.

ONGC discovered lignite in North Gujarat, Rajasthan and north parts of the country at depths greater than 700 m while searching for hydrocarbons [17]. In north Gujarat, they discovered coal reserves of 63 billion tonnes at depths ranging from 700 to 1700 m with a seam thickness of 5–50 m [17].

The statewise lignite reserves are shown in Table 3. Tamil Nadu and Pondicherry have the largest lignite reserve. Gujarat and Rajasthan also have potential quantity of lignite [18]. In later sections the suitability of these lignites for UCG will be discussed.

2.2. Properties of Indian coals

Coal deposits in India are of two distinct geological ages. The earliest coal deposits are of the Permian age formed

Table 3
Statewise lignite reserves in India [17]

	State	Reserve (million tonnes)
1	Tamil Nadu and Pondicherry	26 154
2	Gujarat	1505
3	Rajasthan	1467
4	Jammu and Kashmir	128
5	Kerala	108
	Total	29 362

about 270 million years ago, when South Africa, South America, Antarctica, Australia, India and Madagascar formed a landmass called Gondwanaland. Coals formed in Gondwanaland are known as Gondwana coal. The other deposits are of the Tertiary age (30–60 million years age) [19].

Indian coal is mostly of sub-bituminous rank, followed by bituminous and lignite (brown coal). The ash content of coal ranges from 35% to 50%. Indian coal is mostly of the non-coking variety. Grading and pricing of non-coking coal can be done either by GCV (gross calorific value), NCV (net calorific value) or UHV (useful heating value). UHV can be computed by using an empirical formula developed by the Central Fuel Research Institute (CFRI) [20].

$$\text{UHV in kcal/kg} = [8900 - 138 \times (\%\ \text{ash content} + \%\ \text{moisture content})]. \quad (1)$$

If the moisture content of coal is less than 2% and the volatiles are less than 19%, the UHV calculated by the above formula is reduced by 150 kcal/kg for each 1% reduction in volatile content below 19%. Both the moisture and ash content are determined after equilibrating at 60% relative humidity and 40 °C temperature as per the relevant clauses of the Indian Standard Specification No. IS: 1350-1959. Depending on the UHV, Indian coal is classified as A, B, C, D, E, F or G grade. The grading of non-coking coal based on UHV is given in Table 4. The ultimate analysis of the coal from seven power plants in India shows that the ash content of Indian coals is 30–40% [20].

Table 4
Non-coking coal grading [15]

Coal grade	UHV range (kcal/kg)
A	>6200
B	5600–6200
C	4940–5600
D	4200–4940
E	3360–4200
F	2400–3360
G	1300–2400

2.3. *Current utilization of Indian coal*

India is the third largest producer of coal in the world compared with China at first place and the US at second. The coal in India is under the Government sector. The mining, exploitation and utilization of coal are done by various Indian companies in which CIL and its associated companies are the major ones [16]. In addition to CIL, the NLC operates the Neyveli mines in Tamil Nadu State, Singareni Collieries Ltd. operates the bituminous mines in Andhra Pradesh and Tata Iron and Steel Company (TISCO) operates mines in Bihar to supply coking coal to their own steel plants. CIL is divided into a number of subsidiaries for operational purposes. These are Eastern Coalfields Ltd. (ECL), Bharat Coking Coal Ltd. (BCCL), Central Coalfields Ltd. (CCL), Northern Coalfields Ltd (NCL), South Eastern Coalfields Ltd. (SECL), Mahanadi Coalfields Ltd. (MCL) and Western Coalfields Ltd. (WCL). There is also another principal subsidiary of CIL, the Central Mine Planning and Design Institute Ltd. (CMPDIL).

Currently power sector, defence, railways, fertilizer, steel including sponge iron and pig iron and other metallurgical industries, cement, aluminum industries and paper industry are the consumers of coal in India [16].

Though the coal is a prime commercial fuel in India for power and industry, its distribution and availability is not uniform all over the country causing the problem of long distance transportation and storage. The coal contains high volatile matters (up to 30%) and high ash (up to 40%). Association of the unwanted overburden material in addition to the production of up to 30% fines and slacks has led to an increase in the operational and maintenance cost [17]. Due to its poor quality and uncertain supply, the rate of coal consumption is decreased and it is replaced by petroleum products. For the economic utilization of such coal UCG is a suitable method. In the following section various issues involved in UCG are discussed in brief along with the suitability of UCG for the efficient utilization of Indian coals.

3. Underground coal gasification

UCG typically consists of two adjacent bore holes drilled into a coal seam and pressurized oxidant such as air or oxygen/steam are used for ignition of coal seam [6]. The oxidant and the gasifying agent are fed through the injection borehole and the combustion and gasification products are recovered from the production bore hole. Injecting oxygen and steam instead of air produces the most useful product gas, since the dilution effect of nitrogen is avoided. The main constituents of the product gas are H_2, CO_2, CO, CH_4 and steam. The proportion of these gases varies with the type of coal and the efficiency of the gasification process. Fig. 1 shows a schematic of the UCG process [21].

The successful application of such a process would provide a low to medium BTU gas (100–300 BTU/SCF), depending on whether air or an oxygen–steam mixture is used. In China, UCG is used to generate low and medium heating value gas for steam raising, domestic cooking, domestic hot water and industrial heating [7].

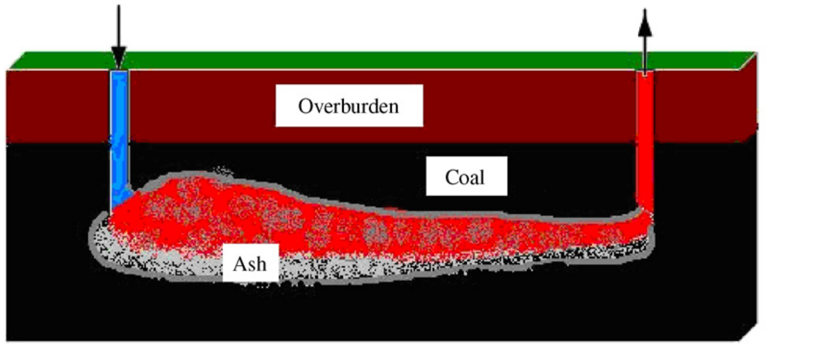

Fig. 1. Schematic of UCG process.

The major advantage of gasification is that coal is converted into a gaseous fuel that is easy to handle and is a clean form of energy. The synthesis gas produced from coal gasification has a wide range of applications. It can be used in a combined cycle system for the efficient and clean generation of electric power. It is also suitable for the manufacture of hydrogen and chemicals such as ammonia, methanol, acetic acid and so on [6,8]. It can be used in multipurpose plants as well for the simultaneous production of electric power, chemicals, fertilizers and fuels. The gas produced can also be used to make synthetic fuels by the gas to liquids (GTL) process.

Reviews of UCG are given by Gregg and Edgar [25] and in many reports from the Department of Trade and Industry (DTI) of the UK [7,22,23]. Here we are not giving the details of each of the process parameters. Our main goal is to study efforts in the direction of UCG in India and to compare the Indian coals with the coals used in successful UCG processes worldwide.

3.1. The major issues in the use of UCG technology

UCG requires an understanding of various aspects of the selected site. The geology, hydrology, mining, drilling, exploration, chemistry and thermodynamics of the gasification reactions in the cavity are important parameters for successful operation. An exchange of knowledge between the various fields is necessary. Before starting UCG, many issues should be considered. Some of them are:

1. Exploration of the UCG site.
2. Choice of a suitable drilling technique.
3. The gasification process (air blown versus O_2 blown).
4. The use of the UCG product gas.
5. Environment and safety.
6. Economics.

3.1.1. Exploration of the UCG site

The potential of the UCG site can be estimated by identifying the geological structure of the coal seam, its depth and thickness, quantity and quality of coal available. In the UK for the UCG site the following selection criteria are used by DTI [7]:

(i) Coal seam $>$ 2 m thick, (ii) depth between 600 and 1200 m, (iii) the availability of good density and bore hole data, (iv) stand off $>$ 500 m from abandoned mine working license areas and (v) greater than 100 m vertical separation from major aquifers.

A good knowledge of the adjacent strata is required to ensure well bore and environmental integrity. The explorations present no exceptional technical problems for the UCG process though there is always a chance that the site may get rejected as the study proceeds, due to the presence of a surrounding good quality water aquifer, low strength overburden or discontinuous coal seam layers. The cost of exploratory drilling and 3D seismic survey is high but is necessary for successful UCG operation [22].

3.1.2. Choice of a suitable drilling technique

A good drilling technique is necessary to connect the injection well and the production well. The cavity between these two wells is considered as the gasification reactor. Three methods that have been developed for this purpose are as follows [22]:

1. *Air pressurization between two vertical holes:* This method is used in the trials of Chinchilla (Australia) and the former Soviet Union (FSU) sites. This has been operated at large scale ($>$ 200 MWe). A recent pilot project (1999–2003) at Chinchilla was successful and an international company now offers it as a commercial process.

2. *Man-built galleries in the coal:* This is used in China to utilize remaining coal after mining.

3. *Directional drilling in the coal seam with controlled injection*: This method is used in the US and European field trials. Directional drilling is more costly to construct but possesses the advantage that basic drilling and completion technology is available from the traditional oil and gas industry. With this method it is possible to get sustainable gasification over long inseam wells ($>$ 200 m), branch drilling of borehole networks for commercial scale operation, and control of a large gasification process using

movable injection in simultaneous channels known as Controlled Retractable Injection Procedure (CRIP).

These methods have been demonstrated in single channel configurations. The choice of a suitable method is necessary for successful UCG operation. CRIP may be suitable due to the available robust technology and possibility of exercising good control over the process.

3.1.3. *Gasification process*

The product gas obtained in the UCG process depends on the temperature, pressure and gasifying agent used. For a low heating value product gas air–steam may be used, whereas for medium to high heating value gas oxygen–steam is used. Chinchilla (Australia) and Chinese trials used air to produce a dry gas of calorific value 3–5 MJ/m^3, whereas pure oxygen at high pressure in the Spanish trials yielded 13 MJ/m^3 of dry gas after gas clean up [23]. Oxygen production has a high energy demand but the benefits are improved gasification stability, better cavity growth and 80% reduction in the volume of the injection gases that need to be compressed [23]. Oxygen is required for any high pressure UCG operation for the reason of the cavity growth and pre-combustion CO_2 capture. The cavity made using any drilling technique serves as a reactor. The major reactions taking place in the reactor are pyrolysis, combustion, gasification, gas phase oxidation and water gas shift reaction. For obtaining constant gas composition and specific gases in the product, kinetics and thermodynamics of these reactions must be well understood [24].

3.1.4. *The use of the UCG product gas*

The main uses of the UCG product gas are:

1. *Fuel gas used for electricity generation*: The UCG operation is optimized to produce a high calorific value product gas for this purpose. The gas turbine (simple or combined cycle) and boiler plant (alone or as supplementary fuel) can be used for power generation [9].

2. *Syngas for synthesis of chemicals or liquid fuels*: The conditions in UCG operation may be manipulated to produce high hydrogen content in the product gas, typically a H_2:CO ratio of 2:1 is optimal. The syngas is used for the manufacture of crude oil equivalents (diesel, naphtha and wax), other liquid fuels (DME, methanol), ammonia and methane [9].

The gas obtained by UCG of low grade coal has mostly been used for power generation in the past. The gas produced at Angrensikaya [24] and Chinchilla [6] are used for power generation. The Chinchilla UCG–IGCC project is designed for maximum power generation. The by-products along with power generation favor the economics of the project. The output of the fully developed Chinchilla project will be as shown in Table 5 [6].

UCG operation in Chinchilla is the longest in duration and the largest outside Russia. The UCG technology was provided to Linc Energy by Ergo Exergy Inc. (Canada), and originated from the former USSR [6].

Table 5
The output of the fully developed Chinchilla project [6]

Product	Output	Energy
Electricity		67 MW
Gas	800 million Nm^3/annum	4.4 PJ/annum
Hydrocarbons	15 000 tonnes/annum	0.6 PJ/annum
Phenols	3700 tonnes/annum	–
Anhydrous NH_3	1500 tonnes/annum	–
Clean water	200 Megaliters/annum	–

3.1.5. *Environment and safety*

The various environmental issues associated with UCG are:

1. *CO_2 emissions*: In the UCG process CO_2 separation from the product gas and storage are the major concerns. CO_2 is produced in significant amounts during the gasification. CO_2 must be captured before venting to the atmosphere and stored or utilized for various applications. The higher pressure of the gas is an advantage offered by UCG for CO_2 storage. CO_2 sequestration work is under development internationally via the Intergovernmental Panel on Climate Change (IPCC) and Carbon Sequestration Leadership Forum [22].

2. *Groundwater contamination*: The UCG site should be carefully evaluated for ground water contamination. The UCG site should be away from the water aquifers. Detailed analysis is needed and after UCG start up, regular check up of the water near the UCG site should be done [22].

3. *Surface subsidence*: The multiwell technology can be used to reduce the chances of surface subsidence. The bore diameter in UCG is smaller than in usual mining operations. So there are less chances of surface subsidence when compared to conventional coal mining [22].

3.1.6. *Economics*

The size of the coal resource is a major commercial factor for the development of the underground coal gasification process. The market for the product gas is the second major factor for commercial development of UCG. If the markets for utilizing the gases are located near the gasification site then gas can be economically transported. The power or chemical plant should be nearby to utilize the product so that transportation losses are minimized. Specific economics of UCG for India are discussed in Section 4.6.

3.2. *UCG field trials*

Various countries have entered into the field of UCG to utilize their vast reserves of unminable coal. Before undertaking a commercial scale project the technical feasibility of the process should be confirmed by carrying out field experiments. DTI of the UK have supported the European trials and followed it up with a series of desk studies (1999–2005) [10]. A fully operational UCG trial at a depth of 1200 m was undertaken from 1981 to 1986 in France. An UCG trial at a depth of 860 m was carried out from 1979 to 1987 at Thulin in Belgium [24,26]. An UCG trial at a depth of 500–700 m was also carried out at El Tremedal in Spain from 1989 to 1998 [23]. The Commonwealth Scientific and Industrial Research Organization (CSIRO) has undertaken a number of UCG research projects in Australia [6,7,27]. A commercial trial was started in 1999 at a site near Chinchilla, Brisbane, at a depth of 130 m and a 40 MW power plant was constructed. The UCG engineering research center at the China University of Mining and Technology (CUMT), Beijing, had undertaken several trials at Xinhe mine, Xuzhou in 1994 and Liuzhang mine, Tangshan in 1996 using the developed process and are capable of producing a gas with a heating value of 4.5 MJ/m^3 [28]. Other trials are in progress at Xinwen, Suncan, Yilan, Yima, Hebi, Panzhihua, Fuxin and Xiezhuang [5]. Russians began their UCG trials in 1933 and have considerable experience in shallow (< 200 m) UCG technology. They have operated UCG plants having a capacity up to 1000 MW [7,21]. Up to 1979, three commercial scale plants were operated at Shatsky, Angren and Yushno-Abinsk [29]. The USA has conducted more than 30 experiments on underground coal gasification between 1972 and 1989 for depths less than 300 m [22,29–31]. The various trials and their details are presented in Table 6. The properties of coals utilized for the UCG field trials are shown in Table 7. The product gas composition from the UCG trials is shown in Table 8 [32]. In Section 4, comparison of the UCG field trial coals with Indian coals is made, in order to determine feasibility of UCG for India.

3.3. Theoretical modeling of the UCG process

To theoretically support the results obtained from field trials and to carry out feasibility studies, several modeling and simulation exercises have been carried out in the USA, Russia and China. There have been two aspects of modeling UCG processes, one of which deals with determining concentration, temperature and pressure profiles and the other, which deals with determining the cavity growth, subsidence and other such mechanical aspects. All the existing models either consider the UCG channel as a packed bed or a free channel where the reactions only take place at the wall [33–40]. Lawrence Livermore National Laboratory (LLNL) had carried out extensive modeling and simulation work for more than a decade to support their field trials [41] in the 1980s. Perkins and co-workers have developed a detailed computational fluid dynamics (CFD) model of UCG, which incorporates many complex behaviors like water influx, cavity growth and so on [42]. However, there is room for more work in the theoretical modeling of UCG, particularly aimed at optimization of inlet conditions.

4. Feasibility study of UCG in India

In this section, Indian coal and lignite seam properties like depth and thickness are discussed. The previous UCG

Table 6
Summary of UCG field trials with coal type and thickness [21,30,39,40]

Location	Coal type	Thickness (m)	Depth (m)	Year	Gas produced in 1963 ($m^3 \times 10^6$)	Comment
Lisichanskaya	Bituminous	0.44–2	60–250	1948–1965	220	Discontinued due to thin seam
Yuzhno-Abinskaya	Bituminous	2.2–9	50–300	1999–current	290	Used for heating
Angrensikaya	Lignite	2–22	120–250	1957–current	860	Used for power generation
Podmoskovnaya	Lignite	2.5	30–80	1946–1953	–	Coal exhausted in 1953
Shatskaya	Lignite	2.6–4	30–60	1963–1956	–	Abandoned due to technical problems
Sinelnikovsky	Lignite	3.6–6	80	–	–	–
Chinchilla (Australia)	–	8–10	130	1999–2004	155 000 Nm^3/h	UCG–IGCC and multiple wells (8)
Tremedal (Spain)	Sub-bituminous, lignite	2–5	530–580	1989-1998	–	–
France	Anthracite	–	1200	1981–1986	–	Well link by combustion and hydrofracture were unsuccessful
Belgium	Anthracite	–	860	1979–1987	–	Difficulties in completing gasifying circuit
Newman Spinney (UK)	Sub-bituminious	0.75	75	1959	–	Four bore holes of 140 m and diameter 0.3 m
USA (Hanna 2)	Sub-bituminious	6.8	90–120	1973–1974	4800–10 200 kmol/day	The best instrumented UCG test.
USA (Hoe Creek)	Sub-bituminious	7.6	38	1976–1979	–	Explosive charges were used to create linkage path

Table 7
The product composition of UCG gas [20,30]

Location	UCG gas composition (%)								Avg. heating value (MJ/m^3)
	CO_2	CO	H_2	CH_4	H_2S	C_mH_n	O_2	N_2	
Lisichanskaya	26.7–28	6–8	13–15	2–2.4	1.6–1.9	0.3	0.2	46–49	3.3
Yuzhno-Abinskaya	14.3	10.6	14.1	2.3	0.03	0.2	0.2	58.3	3.8
Angrensikaya	19.5	5.4	17	2	0.4	0.3	0.6	54.8	3.52
Podmoskovnaya	17.6	6	15.2	1.8	1.2	0.2	0.5	57.8	3.36
	28.4	15.6	35	1.8	3.5	–	–	15.7	6.39 (65% O_2)
Shatskaya	16.9	6.1	15.1	1.5	1.2	0.2	0.5	58.5	3.35
Sinelnikovsky	20.5	2.1	11.6	1.3	0.3	0.1	0.5	63.6	2.6
Hanna.2	12.4	14.7	17.3	3.3	0.1	0.8	–	51.6	1620 kcal/m^3

Table 8
The properties of the UCG trial coals [21,30,39,40]

Country	Location	Proximate analysis (%)				Ultimate analysis (%)					Heat value (kcal/kg)
		M	Ash	VM	FC	C	H	O	N	S	
US	Blue Greek seam		6.79	36.15	57.06	76.50	5	8.64	1.71	0.7	13 992
	Hanna no.2	–	26.26	36.07	37.67	54.81	4.45	12.30	1.43	0.75	9580
	Flix no.2(3)	–	5.8	45.96	48.24	69.23	5.24	17.79	1.45	0.49	11 960
	G win	–	15.41	20.63	63.96	74.67	4.25	3.38	1.11	1.18	13 323
	Flix no.2(1)	29.2	6.37	31.9	32.90	47.41	3.53	11.95	0.91	0.02	–
France	–	1.4	3.4	28.6	–	80.13	4.71	6.27	1.47	0.63	78.65
China	–	4.18	7.61	23.08	–	72.72	4.71	8.32	1.13	1.33	28.14–29.31 (MJ/kg)
		0.02–0.18	16.15–19.50	28.68–30.01	31.71–53.74	–	–	–	–	–	–
UK	Newman Spinney	6	6	35	53	–	–	–	–	–	–
Spain	Tremendal	22.2	14.3	27.5	36	–	–	–	–	–	18.1 (MJ/kg)
Australia	Chinchilla	6.8	19.3	40	33.9	–	–	–	–	–	–
USSR and Russia	Lisichanskaya	12–15	7–17	39–40	–	–	–	–	–	–	20–23
	Yuzhno-Abinskaya	2.5–8	2.3–5.2	27–32	–	–	–	–	–	–	28–30
	Angrensikaya	35	12-20	33	–	–	–	–	–	–	15.10
	Podmoskovnaya	30	34.30	44.50	–	–	–	–	–	–	11.80
	Shatskaya	30	26	38.10	–	–	–	–	–	–	11.10
	Sinelnikovsky	55	23.80	64.50	–	–	–	–	–	–	8.0

studies in India are reported along with the current selection of coal blocks for UCG by various agencies. Indian coals are compared with other coals, which are used for the worldwide UCG trials, based on seam depth, thickness, coal properties and quantity of coal available. The government policy for UCG and public issues are mentioned in brief.

4.1. Coal depth, quantity and thickness in India

The coal occurrence at various depth levels in India is categorized in Table 9. A total of 62.74% of the coal deposits lie at a depth of 0–300 m, 30.07% at 300–600 m and 7.19% coal is at a depth of 600–1200 m [19]. The coal at greater depths (> 300 m) can be used by UCG technology economically.

The coal seams in West Bengal and Madhya Pradesh are suitably deep and have a thickness > 2 m. The coal quantity proved at these places is also sufficient to start UCG if the mining of the coal seams becomes more difficult. The coal seams in Maharashtra, Assam and Arunachal Pradesh are 0–600 m deep and also have thickness > 2 m but the quantity of available coal is less compared to West Bengal and Madhya Pradesh.

Table 9
Indian coal reserves at various depths (in million tonnes) [18]

Depth (m)	Proved reserve	Indicated reserve	Inferred reserve	Total reserve	% Total reserve
0–300	54 627.35	54 242.51	20 519.91	129 389.77	62.74
300–600	18 929.82	25 694.76	17 384.94	62 009.52	30.07
600–1200	1560.58	9141.99	4137.64	14 840.21	7.19
Total 0–1200	75 117.75	89 079.26	42 042.49	206 239.50	100

4.2. Lignite depth, quantity and thickness in India

The lignite reserves in India are compared with the worldwide UCG trials of lignite. Gujarat, Rajasthan and

Tamil Nadu have large lignite reserves [18], which can be economically utilized by UCG. The quantity of lignite is sufficient to start UCG pilot studies (Table 3). In north Gujarat, 63 billion tonnes of lignite is found at a depth of 700–1700 m, having a thickness of 5–50 m. If the same criteria (see Section 3.1.1) for UCG site selection are applied in India as that in the UK, then depth and thickness of these coal reserves are favorable for UCG. Detailed comparison of properties of these coals with field trial lignites is done in Section 4.5.

4.3. Previous studies for UCG in India

UCG studies were undertaken in the 1980s in India as National Projects. Three regions were studied namely Mehsana in Gujarat (deeper lignite 500–1700 m), Merta Road in Rajasthan (shallow lignite 100–200 m) and Bihar (now Jharkhand) (bituminous coal) [43]. Soviet experts selected two sites South Sayal and Medni Rai blocks, and Merta Road block of Rajasthan for generation of additional data, out of 13 sites. On the basis of additional data, Medni Rai block was rejected. Experts concluded that the lignite deposits at Merta Road are feasible for UCG. However, this area was dependent solely on water aquifers above and below the lignite bed. Due to the possibility of pollution of these water aquifers, pilot studies and further development of this project were restricted.

ONGC studied prospects of UCG for deeper lignites (600–1000 m) in Gujarat at Mehsana during 1984–1986. They drilled two pilot wells UCG1 and UCG3 at a distance of 10 km north east of Mehsana to get data regarding nature of rock, coal properties and sub-surface strata conditions [43]. Further developments were not reported since then.

4.4. Identification of coal blocks for UCG by ONGC

After a gap of 20 years ONGC India has again undertaken site selection for UCG pilot studies with technical support from SIM Russia [44]. Five coal blocks have been studied. Four coal blocks (Blocks I–IV) were rejected based on hydrological reasons. One block (X-Mine Block) has been found suitable for an UCG pilot study. Blocks I–IV were rejected based on one or more of the following reasons: (1) block was surrounded by water aquifers. (2) Block was discontinuous. (3) Block was enclosed by Basalt. (4) Block was surrounded by water bearing rocks.

If UCG is carried out in Blocks-I and II, during the process of extracting gas from the coal seam, deformation and movement of coal strata would cause the thick basalt blanket to fall off resulting in sectioning and parting of drill strings.

Block V (X-Mine Block) was found to have good lignite reserves. Two major lignite seams were encountered up to a depth of about 300 m. The seams were deposited in thick strata of clay materials, which is a very favorable factor. The lignite seams appeared to be safely isolated from the overlying alluvial aquifer by thick strata of waterproof rocks and this factor excludes possible negative influences on the UCG process. This block has been selected for pilot studies [44].

4.5. Comparisons of selected Indian coal seam properties with field trial coals

UCG field trials conducted worldwide (Table 6) show that the Yuzhno-Abinskaya, Angrensikaya, Podmoskovnaya, Chinchilla and Tremedal trials can be considered as successful field trials. These sites have the following parameters which are important for UCG: depth 30–580 m, thickness 2–5 m, ash 2–34%, moisture 7–35%, volatile matter 27–44% and fixed carbon 12–38%.

Our proposal of Indian coal mines for immediate UCG activity is based on these features. The mines where the depth, thickness and coal properties fall in the above ranges are listed in Table 10. In addition, the Kalol mine in Gujarat listed is very deep. UCG should be ideally used here as conventional mining is not possible.

The depth and thickness of these Indian sites are compared with the successful UCG field trial site of Angrensikaya in Fig. 2. The selected Indian sites have comparable depth and thickness as that of Angrensikaya. The coal properties are compared with Angrensikaya coal in Fig. 3. It shows that Indian coals have low ash content. The fixed carbon is comparable with Angrensikaya, X-Mine block has high moisture content. In a similar way the thickness and coal properties of Sasti-Rajura (Maharashtra) coal are comparable with the Chinchilla trial coal. This Indian site has a depth of 600 m. The comparison of coal properties is shown in Fig. 4.

The Kalol site has a greater depth of 1700 m and its coal properties are comparable with that of Angrensikaya lignite. However, this is a matter for future consideration, as the financial investment in UCG is likely to be initially in the shallower mines.

These sites may be looked upon as potential sites for the application of UCG technology implementation. X-Mine block has already been selected by ONGC based on geology and hydrology, as suitable for pilot studies. For the other sites, geological and hydrological studies must be performed, based on this favorable initial analysis.

4.6. Economics of UCG for power generation

National thermal power corporation (NTPC), India, presented the cost estimation study of an UCG–IGCC power plant at a workshop held at Kolkata, India in 2006 [45]. A 100 MW power plant with coal having a GCV of 3300 kcal/kg was chosen for a case study. The coal seam thickness was assumed to be 2 m.

The following conclusions were reached based on cost estimations using available data—the capital cost for IGCC is estimated as Rs. 850 crores, and for UCG as

Table 10
Potential UCG sites in India [17,18,43]

State	Field/block	Proximate analysis						Depth (m)	Thickness (m)
		M%	Ash%	VM%	FC%	CV (k cal/kg)	S		
Tamil Nadu	Mine-I	45–55	2–9	19–25	17–22	2500–3200	0.7–1.1	319–479	1–20
Rajasthan	Kapurdhi	40–50	5–20	20–30	15–30	2001–3500	–	55–120	5–20
Gujarat	Kalol	23–28	10–20	40–44	30–37	4800–5700	0.2–1.5	700–1700	5–50
Gujarat	Umarsar	27.8	12.7	37.9	21	4180	1–5.7	150–220	0.3–30.5
Maharashtra	Sasti-Rajura(Bhandara)	12	15–18	32	8.2	–	–	600	8.2
–	X-Mine	47	22	12	19	–	–	300	–

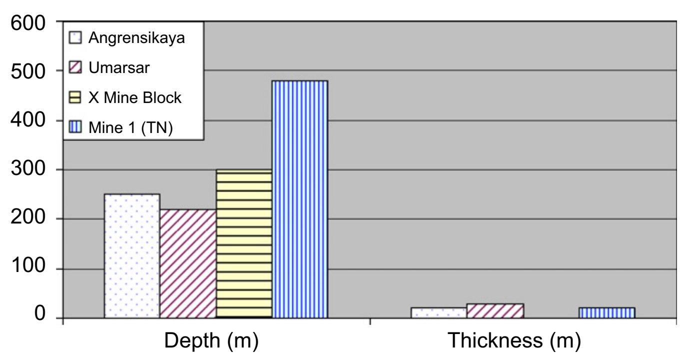

Fig. 2. Comparison of depth and thickness of coal from selected sites in India with Angrensikaya coal.

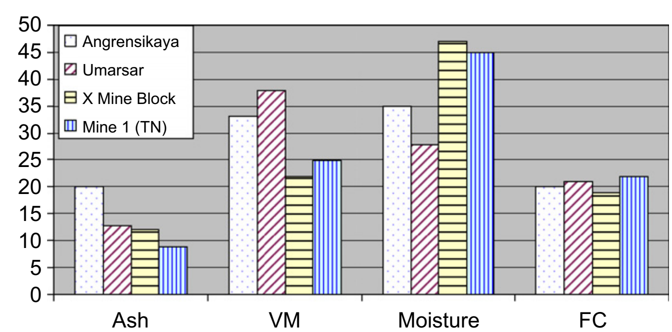

Fig. 3. Comparison of coal properties from selected sites in India with Angrensikaya coal.

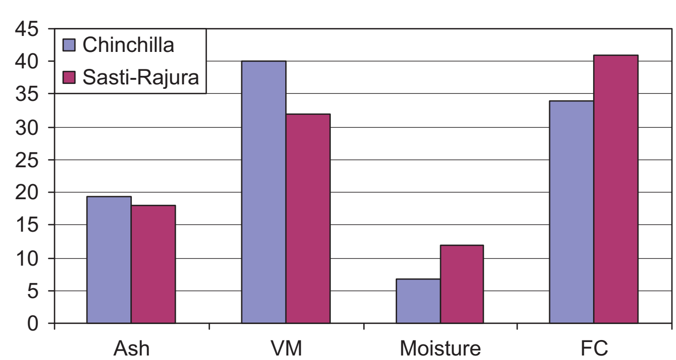

Fig. 4. Comparison of properties of coals from Sasti-Rajura and Chinchilla.

Rs. 640 crores. This is attributed mainly to the additional cost of the specially designed gasifier, and coal and ash handling, in case of IGCC. However, the cost of generation (Rs./kW h) is higher in case of UCG (Rs.3.6/kW h) as compared to IGCC (Rs.2.6/kW h). This is mainly due to the higher fuel cost and lower gross efficiency associated with UCG. Finally, it has been mentioned that COG in case of UCG will be comparable to that for IGCC if the seam thickness is greater than 2 m and the calorific value of the coal is above 3300 kcal/kg.

4.7. *Indian government policy for UCG*

Indian government is in the process of making a policy to allot the coal blocks for UCG. The present rules do not permit UCG as the end use for the allotment of coal blocks. The Ministry of Coal will notify the rule change at the end of this financial year. This would amend the Coal Mines (Nationalization) Act of 1976. After sorting out all the technology and related issues by the interested industry, coal blocks can be allotted based on the data available with the Coal Mining and Planning Development Institute after notification by the ministry [15]. The draft coal vision 2025 envisages the development of UCG [43]. Although there are no specific policies encouraging UCG technology in India, the message from the appropriate ministry is that in the near future such policies will come into place, and that as far as the government is concerned the benefits of UCG especially for India, are well appreciated.

4.8. *Planning and public perception issues*

Since discussions on UCG are at an initial stage, planning and public perception issues are to be discussed at a later stage of the commissioning of the projects. This involves educating the public about UCG, its benefits and possible effects. It should be noted that a detailed study conducted in the UK for public perception issues indicated the importance of the local public opinion for such projects [46]. Such type of studies should be conducted in India at favorable sites.

Considering the potential in India for UCG, we believe that the time is now ripe for extensive laboratory experiments and mathematical simulations on Indian coals, followed by field trials at specific sites. UCG could be particularly useful in India because of the high ash content of coal, i.e. avoiding need for coal washing, transportation of ash, disposal of ash, problems with combustion and surface gasification. However, before starting an UCG project, complete environment and risk management studies should be undertaken. To the best of our knowledge information on these aspects is not available in the open literature, as yet.

5. Summary

India is the third largest producer of coal in the world. India has 253 billion tons of coal reserves and a significant portion is deep underground. Indian coal is of bituminous, sub-bituminous and lignite type. The high ash content and poor quality of these coals leads to operational problems in industries. Hence, the consumption of coal is reduced. To utilize the vast coal reserves underground coal gasification is a promising technology. UCG can utilize low-grade coal in India economically. After comparison of the coal in India with the coal used in worldwide UCG trials, it seems that some of the low-grade coal seams are suitable for UCG particularly in Gujarat, Rajasthan and Tamil Nadu. X-Mine block selected by ONGC India recently for UCG studies has comparable depth and coal properties as that of the previous field trials. Although the coal seam depths, thickness and quantity of coal are favorable for UCG in many places in India, properties such as ash and moisture content may need further consideration.

Furthermore, additional information regarding the environment and safety issues needs to be generated in order to fully evaluate the candidature of any potential site for UCG. Theoretical studies are also required for the prediction of UCG gas composition and coal consumption to support the pilot studies. Pilot studies will enable detailed analysis of the UCG process in India based on coal type, geology and hydrology of the particular site. Coherent inputs are required from research institutes and industries in order to take UCG activity forward in India.

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