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Implementing Clean Coal Technology Through Gasification And Liquefaction – The Indian Perspective

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Abstract: Coal is the prime fossil fuel in India and continues to play a vital role in the energy sector. Coal accounts for 60% of the commercial energy needs and 70% of electrical power in India comes from coal. Coal combustion emits large amounts of harmful gases and is also responsible for global climate change. Indian coals being of drift origin, contains large quantities of impurities which are intimately mixed, and poses serious challenges in implantation of conventional clean coal technologies. Coal conversion in the form of gasification and liquefaction provide better alternatives in optimum utilization of our resources along with minimizing the emissions significantly.
Keywords: Clean coal technology; conversion, gasification; liquefaction.

Introduction

India ranks fourth in coal reserves, with estimated reserves of over 285 billion tonnes up to a depth of 1200 meters as of April 1, 2011. It also has significant lignite reserves of over 40 billion tones[1]. Currently it ranks third in coal production behind China and USA. India's coal reserves provide a secure economic resource for generation of electricity and meeting the energy demands of the steel, cement, and manufacturing industries. In fact, coal accounts for 60% of the commercial energy needs and 70% of electrical power in India comes from coal[2]. However, coal combustion emits particulate matter, sulphur dioxide, nitrogen oxides, mercury and other metals, including some radioactive materials, in a much higher proportion than oil or natural gas and, therefore, causes local and regional pollution problems in the form of acid rain and increased ground-level ozone levels, and global climate change. The environmental impacts of coal extraction, transportation and utilization have serious impacts on the landscape, rivers, water tables and other environmental media. Use of coal for combustion applications generate relatively higher emissions of CO_2 than other fossil fuels, since coal's ratio of hydrogen atoms over carbon atoms and power generation efficiency are relatively low compared to other fossil fuels. Coal is also responsible for methane emissions, particularly from mining activities[3]. Therefore, there is global attention in adopting newer and cleaner technologies.

Clean Coal Technologies (CCTs) are defined as 'technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use'. These technologies reduce emissions, reduce waste, and increase the amount of energy gained from each tonne of coal. CCT programmes are being vigorously pursued by many countries, with many billions of US dollars equivalents being spent annually on developments in utilization techniques. These technologies will enable coal use to be increasingly efficient and environmentally acceptable as a vital world energy source throughout the next century.

Coal Energy In India

India has a vast energy infrastructure of coal, starting from coal mining to extraction, and coal transport to coal utilization in power plants. In view of India's rapid economic growth at 8–10%, the energy requirement to meet the basic needs of its people is also growing. Power generation is majorly dependent on coal. The power sector is the largest consumer of coal in India. It accounts for nearly 66% (72% including Captive) of the demand. Of 185.5 GW (November 2011) of installed power generation capacity, coal-based capacity constitutes 55% while contribute to more than 70% of power generated. The Integrated Energy Policy projects an almost four- fold increase in the total energy requirement by 2031-32 with a peak demand of 733GW which will require augmenting total installed capacity to 960GW. Thus, the power sector is expected to remain the key driver for coal demand in future also[4]. Power generation is the major source of carbon emissions, which accounted for about 38 per cent of total GHG emissions in 2007. Emission from a power plant depends on total generation, fuel consumption efficiency, and fuel quality. Of the 200 thermal power plants of different size and capacity, about 40 per cent are older than 20 years and would cause more pollution. Most of the installed coal-based power plants up to 500 MW are based on pulverized fired units. A few circulating fluidized bed boilers using high sulphur lignite are also being operated.

The run-of-mine (ROM) coal varies from 0-500 mm in size. It contains mineral or inorganic matter as extraneous and inherent impurities, which needs to be removed. For commercial applications, high rank coal is preferred. But in our country, reserves of high rank coals are limited compared to low rank coals, which are abundantly available. Hence, technology advancements are taking place in the use of low grade coals. Clean coal technologies are categorized into: (i) Pre-combustion or Coal beneficiation, (ii) Coal combustion, (iii) Post-combustion. (iv) Coal conversion[5]. The clean coal technology is of the utmost importance because: (i) coal is abundant and will remain a major source of energy for future years, (ii) emission from coal based generation is a matter of serious concern. Thus, clean coal research has begun to improve the quality of non-coking coal at the pre-combustion stage for use in power generation by value addition. Research and pilot studies are on to adopt new coal combustion and conversion technology for improving efficiency of coal utilization, and reduce carbon dioxide emission though its capture and storage. Though several advance methods of coal beneficiation have been developed, still it is very difficult to achieve the desired level of cleaning, because the impurities present in coal are intimately mixed. Many of the CCTs implemented in the combustion and post combustion stage achieve a greater degree of control in removing SO_2 than NOx. The conversion processes, with less emission, lesser ash disposal problems and improved efficiency, therefore offer a better alternative compared to other processes.

Coal Conversion Technologies

These technologies comprises of converting coal into gas through gasification and into oil through liquefaction. The coal gasification can be categorized into surface gasification and underground gasification. Some of the other alternative applications are fuel cells and magneto-hydrodynamics. Coal conversion processes reduce pollution and increase efficiency, but adds to infrastructure needs for coal suppliers/users.

Surface Coal Gasification

Surface gasification of coal is a method of converting coal into gas in gasifiers by reacting the raw material at high temperatures with controlled amount of oxygen or steam for production of 'syngas' for various industrial purposes. Coal gasification is considered an important strategy for low carbon energy development. The product of the gasification process is a producer gas, which is a mixture of carbon monoxide, hydrogen, and some methane. It can be utilized in ways similar to natural gas in an environment friendly manner. Its calorific value (33.12 MJ/m^3) is lower than natural gas (49.0 MJ/ m^3). Many by-products like ethanol, methanol, DME etc. and the gas produced is used as feedstock for manufacturing urea, Ammonium Nitrate etc. Gasification is a more efficient way of using fossil fuel than directly burning the same. Now more advanced and highly efficient gasification technologies are available for application in the industries[6]. Gasification reactors are designed to suit coal characteristics. Three well-known configurations are the fixed bed, fluidized bed, and entrained bed systems[5,7].

Fixed Bed Gasifier reactor has different zones for each operation such as drying, devolatilizing, gasification, and combustion. Coal of 10–50mm size is fed from the top and air or oxygen is blown through the fuel bed. The crude gas leaves the gasifier from above. This type of gasifier obviates the need for a heat exchanger, has lower oxygen consumption, and has the lowest energy requirement of all gasification processes. This technology has been commercialized and about 200 fixed bed gasifiers are operating around the world. The best-known name commercially is Lurgi Process or British Gas Lurgi.

Fluidized Bed Gasifier works on the counter-current principle and allows coal particles to move vigorously. It consists of a vertical cylindrical refractory lined vessel with recycle cyclone. The temperature in the reactor goes up to 850–1,050°C. It is a non-slagging gasifier and has been tested with all types of coal and lignite, and is found attractive for high ash coals as well as high reactive coals. The chemical reaction in this gasifier is accelerated by turbulent mixing and close contact. There are no separate de-gasification and gasification zones. Dust-laden gas leaves the reactor at the top, and is cooled and purified before use.

Entrained Bed Process is the third configuration. Finely ground coal of 0.1 mm is entrained at high temperatures of the order of 1,400 to 1,600°C. Coal gasifies instantly and volatile matter in coal also contributes to the gas at the reaction temperatures. The product gas has almost 80 per cent of the energy of the feed coal. The ash in the coal melts and runs down the refractory-lined walls of the gasifier as liquid slag in the water tank. Different versions of entrained bed gasifiers have been developed as Koppers-Totzek and five different versions of it are Shell, Texaco, Dow, Prentflo, and Destec.

The first coal gasification test facility in India came up when a 10 MW captive power plant used gas from coal washery rejects by Bharat Heavy Electricals Ltd. (BHEL) at the TISCO Jamadoba Colliery in 1987. A number of trials have been made subsequently. Fertilizer plants at Ramagundum and Talcher installed entrained bed gasification technology for utilizing indigenous coal for production of ammonia. However, these plants have encountered some practical difficulties and were closed down for economical considerations. From the experience gained from operating and testing facilities, two CFB gasifiers of 390 tonnes/hr capacity have been installed successively at Gujarat Industries Power Co. Ltd. for their Surat Lignite Power Plant (SLPP). The Neyveli Lignite Corporation Ltd. has also installed a circulating fluidized bed gasifier based on the Wrinkler process to demonstrate the use of lignite. Coal India and Gas Authority India Ltd. have jointly started work in 2010 to set up a large surface coal gasification plant.

Underground Coal Gasification

Underground coal gasification (UCG) is *in-situ* gasification of coal/lignite deposits from deep and/or un-mineable or non-mined coal seams for production of synthetic gas (syngas) for power generation, production of synthetic liquid fuels, natural gas or chemicals. 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[8-12]. The main gasses produced are carbon dioxide, methane, hydrogen and carbon monoxide. The gas can be processed to remove its CO_2 content thereby providing a source of clean energy with minimal greenhouse gas emissions. UCG has the potential to eliminate the environmental hazards associated with ash, with open pit mining and with green house gas emissions if it is combined with utilization of CO_2 that produced during the process.

Underground Coal Gasification Process

The process of gas recovery is similar to oil or gas recovery from the interior of the earth. A simplified process is depicted in Figure 1. Four major technical steps involved in UCG recovery are:

- Drilling a pair of vertical holes, known as injection and production boreholes, into the coal seams.
- Linking boreholes by forward combustion, reverse combustion, man-built galleries (horizontal drilling), or high power lasers.

- Igniting coal seam using Controlled Refractory Injection Point (CRIP) technology.
- Injecting gasifying fluids such as air, oxygen, or steam for the recovery of coal gas.

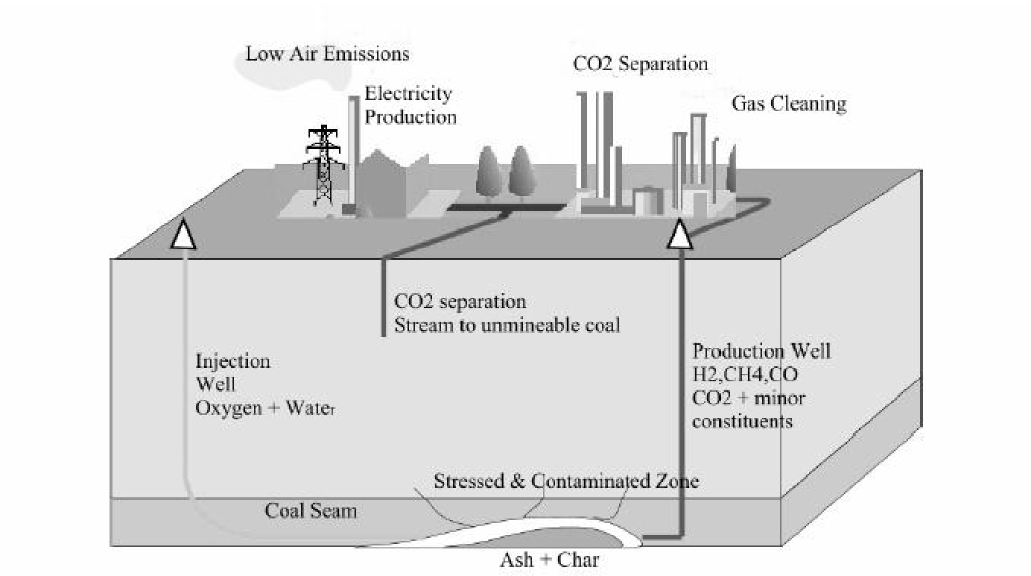

Figure 1: Simplified Underground Coal Gasification Process[13].

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 products 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.

UCG potential

All the geological resources are not mineable and all mineable reserves are not extractable. The mineability and extractability of a deposit depends on the grade and pricing, available technology of extraction, infrastructure availability, safety and environmental considerations etc. CMPDI broadly assess the extractable reserves considering the formula:

$$Estractable\ Reserves = \frac{0.9 \times Proved\ Res. + 0.7\ \times Inferred\ Res. + 0.4\ Inferred\ Res.}{4.7}$$

- Detailed exploration connotes a confidence level of 90% of the reserves established.
- Regional exploration establishes the resources in Indicated and Inferred categories. The Association of German Metallurgists and Mining Engineers place a 70% confidence level to Indicated and 40% to Inferred Resources.
- A study by CMPDI (July, 2001) shows an average Reserves to Production (R : P) ratio as 4.7:1. While the R : P ratio of the individual mine/block will vary widely[14].

As a result of exploration carried out up to the maximum depth of 1200m by the GSI, CMPDI, SCCL and MECL etc, a cumulative total of 285.86 Billion tones of Geological Resources of Coal and 40.906BT of lignite have so far been estimated in the country as on 1.4.2011[1]. The details are as given in Table 1. The extractable and un-extractable coal resources are also presented in the Table.

Table 1: Coal and Lignite reserves in India [1]

	Proved	Indicated	Inferred	Total	Extractable	Un-extractable
Coal	114.002	137.471	34.39	285.862	45.231	240.631
Lignite	6.146	25.794	8.966	40.906	5.7816	35.1244
Total	120.148	163.265	43.356	326.768	51.013	275.755

It is therefore sensible to find ways and means to exploit these unrecoverable Coal and Lignite reserves of 275.75 billion tones to meet part of the ever increasing energy demand of the country. In this endeavor a good part of the un-mineable Coal and Lignite deposits can be extracted by using underground coal gasification (UCG). One tonne of coal has potential to generate approx.2500 m^3 of syn gas. If we consider only 10% of unextractable coal and lignite reserves as amenable for UCG i.e. 27.58 BT, a total 68.95 trillion m^3 UCG syngas potential of calorific value 3-5 MJ /m^3 is available.

The advantages of UCG over conventional coal mining and utilization techniques are lesser capital and operating expenditure, less ash disposal problems, reduced NOx and SOx production, utilization of deep and thin coal seams, which are not accessible for mining and could provide an efficient carbon capture and sequestration (CCS) possibility, and increased worker safety. The disadvantages of UCG are migration of VOCs (Volatile Organic Compound) in vapor phase into potable groundwater, upward migration of contaminated groundwater to potable aquifers and changes in permeability of the reservoir rock due to UCG

In India, coal accounts for more than half of the total energy produced. Seeing the current and future demands and the potential depletion of coal reserves in the foreseeable future, alongside the focus on the environment impacts of coal utilization, UCG is one of the most favorable options to mine the reserves which are un-mineable with conventional technology. As mentioned above, India has more than 35% of coal resources locked at depth higher than 300m which are potentially exploitable by UCG.

Indian Status

ONGC signed an Agreement of Collaboration (AOC) with M/s Skochinsky Institute of Mining (SIM), Russia on 25th November, 2004 for implementation of Underground Coal Gasification (UCG) program in India. As follow-up MOUs was signed with various coal companies for accessing the coal/lignite blocks for evaluating their suitability to UCG. After evaluating a number of coal/lignite blocks, Vastan Mine block belonging to GIPCL in Surat district, Gujarat was found suitable for UCG. This site has been taken up by ONGC as an R&D project to establish UCG technology. All the ground work and inputs for pilot construction have been finalized for implementation of UCG pilot at Vastan.

In parallel action, other sites have been taken up for studying their suitability for UCG. ONGC and Neyveli Lignite Corporation Limited (NLC) jointly identified Tarkeshwar in Gujarat and Hodu-Sindhari & East Kurla in Rajasthan. One more site was also jointly identified by ONGC & Gujarat Mineral Development Corporation Ltd, Gujarat (GMDC) viz. Surkha in Bhavnagar Distt., Gujarat. The data of all the fields have already been analysed for evaluating the suitability of these sites for UCG and all the sites have been found suitable for UCG. These projects will be taken up on the basis of learning curve from Vastan project[15].

A tender was floated for selection of a suitable service provider for commercial development of UCG in two identified coal blocks within CIL area, namely Kaitha in Ramgarh Coalfield within CCL command area and Thesgora-C in Pench Valley Coalfield within WCL command area. Good responses were received against both the tenders. The tender, however, could not be finalized on technical reasons and re-tendering has been advised[1]. There are significant reserves of coal at greater depths encountered during the course of oil drilling and these can not be conventionally mined. Such areas should be targeted to develop UCG projects either through PSUs or through JVs or through PPPs[6].

Coal Liquefaction

Conventional crude oil provides 35% of global energy consumption and more oil is used today than at any other time. Demand for oil will rapidly grow, primarily due to industrial growth in developing countries as well as increase in vehicle ownership. Energy security concerns in the oil sector are increasing due to resource constraint, security of supply, political instability and infrastructure difficulties. On the other hand, coal is affordable and widely available. Coal reserves in the world are vast and will be available for the foreseeable future without raising geopolitical concerns. The development of coal to liquids (CTL) industry can serve to hedge against oil-related energy security risk[16].

Coal liquefaction is an industrial process in which coal as raw material is converted into liquid hydrocarbon mixture through chemical reaction, which, under further processing, becomes the desired liquid fuels or chemical feed stock. The liquid fuels produced through this process are suitable for transportation application by the removal of carbon or addition of hydrogen, either directly or indirectly. In this way coal can act as a substitute for crude oil. However, the cost effectiveness of coal liquefaction depends to a large extant on the world oil price with which in an open market economy, it needs to compete.

Direct Liquefaction (DCL): Hydrogen is added to the organic structure of coal, breaking it down to the point where distillable liquids are produced. Pulverized coal is dissolved into a process solvent, then preheated, mixed with hydrogen and fed to the first reactor at high temperature and pressure (typically 460^0C and 170 bar). A second reactor completes the liquefaction, operating at higher temperatures. The reaction catalyst for both the stages may be iron –based one, dispersed in the slurry. Liquid yields may be in excess of 70% of the dry weight coal feed, with thermal efficiencies of around 60 -70%.

Indirect Liquefaction (ICL): Indirect liquefaction also known as Fischer–Tropsch process, involves the complete breakdown of the coal structure by gasification with steam. The composition of this synthetic gas, or, ‘Syngas’ is adjusted to give the required balance of hydrogen and carbon monoxide. Sulphur compounds are also removed at this stage to prevent poisoning of the reaction catalyst as well as to provide low-sulphur transport fuels. The syngas is then reacted over a catalyst over at relatively low pressure and temperature.

The most important property of coal in order to predict liquid yield from coal is the percentage of volatile material in it. The ratio of liquid yield from coal varies between 35 and 45%. One tonne of coal can produce about one to three barrels of oil and 200 to1,000 m^3 of gas. Wide ranges of by-products are obtained in different liquefaction processes. These can be used as chemical feedstock or for industrial process heating. The countries which have made progress in implementing CTL are South Africa, China, USA, Australia, germany and Indonesia. The biggest coal liquefaction plant based on the Fischer–Tropsch synthesis is operated by South Africa Synthetic Ltd. at its Sasol Plant. It has a production capacity of about 1,50,000 barrels of oil per day. In India, laboratory-scale investigations on coal liquefaction began in the 1950s at the Indian Institute of Technology, Kharagpur, with the objective of developing indigenous catalysts. In the Fischer–Tropch synthesis ‘syngas’ was first produced using fixed bed gasification process at 800–900^0C. A number of chemicals as catalysts were tested, including zeolite supported iron catalyst and resulted in the output of 4 litres of oil per day. Oil India Ltd. has undertaken test work, pilot plant runs and feasibility studies on CTL using direct liquefaction technology from Headwaters, USA. Subsequently, it signed a contract with Coal India to set up a commercial-scale coal liquefaction plant of 3.5 Mt per annum coal capacity. Assam coal is considered to be the best for coal liquefaction due to its composition, as about 90 per cent of the coal is directly convertible into fuel. The State is estimated to have about 900 million tonnes of coal reserves. However, coal mining is difficult due to the inhospitable terrains where most of the reserves are located.

However, the CTL era in India really kick started when, in 2008, Ministry of Coal (MoC) offered three Captive Coal Blocks in Orissa for CTL Projects and issued guidelines for allotment of these blocks. It was envisaged that about 1 to 1.5 billion tones of E/F grade coal reserves would be made available over a period of 30 years for this purpose. Estimated run of mine coal production would be 28 to 31 MMT annually for 30 years, resulting in annual production of oil /oil products to the tune of 3.5 MMT. There was tremendous response to this offer, and after a rigourous process by an Inter-Ministerial Group (IMG) the Ramchandi block was awarded to JSPL, while Tata-Sasol JV got the North of Arkhapal Block for CTL Projects. A total investment of about US $ 18 billion is expected in these two awarded blocks with combined production potential of 160,000 bbl/d of synthetic liquid fuel. However, the actual commercial production performance of the proposed CTL Plants will only be known after successful implementation of Pilot Scale Plants.

Conclusion

In India efforts towards clean coal technology development began more than two decades ago, but have not kept pace with the global developments. There have been other barriers and constraints in the advancement of CCT, viz. high cost involved to support development of CCT to proving stage, amenability of advanced technologies, inadequate R&D infrastructure in academic institutions and national laboratories, lack of academic–industry interaction for new coal-based technology and constraints in development of coal blocks in the absence of adequate equipment infrastructure among others. Moreover, many CCTs are proprietary and protected by strong patent regimes. New coal technologies are not proven and involve higher capital investment. In the absence of appropriate marketing strategies for adoption of clean coal for power generation, many new researches have not moved out of the laboratory.

At current production and consumption rate, India has well over 200 years of coal available. Low rank coal with high ash content and non coking type can be economically utilized as feedstock for UCG and CTL projects in India. The gaseous and liquid fuels, thus produced, may help to reduce our import dependence. The challenge of implementing CCT on large scale however, remains as daunting as ever. Though coal gasification and coal liquefaction are less pollution emitting technologies, but for their implementation on industrial scale a number of trade-offs between financial and technological considerations continue, mainly arising from quality of coal resource. There are financial, infrastructural, and regulatory barriers to be tackled in almost entire coal chain starting from coal extraction to coal utilization and pollution abatement.

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