Potential for Underground Gasification of Pakistani Lignite Coal

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(received August 9, 2011; revised October 31, 2011; accepted November 2, 2011)

Abstract. Laboratory scale process of underground gasification of Pakistani lignite has been performed to check the potential of the Pakistani coal for gasification. High permeability and low swelling index of coal are desirable properties for UCG. In Pakistani lignite both properties are found and in case of lignite and brown coal, natural permeability provides adequate linkage. The proximate and ultimate compositions of the samples show that it is of low quality coal with high volatile matter. Coal has been converted into syngas and utilized as the substitute of natural gas and for power generation.

Keywords: underground coal gasification, syngas, Pakistani lignites, Thar coal

Introduction

Coal is the most abundant fossil fuel in Pakistan. After the discovery of the huge coal deposits of 175.5 billion tonnes in an area of 9,500 sq. km in Tharparkar District of Sindh, Pakistan has got a significant position in the list of coal rich countries (GSP, 2001). Unfortunately the huge reserves are not exploited yet, while Pakistani lignites are suitable for underground coal gasification (UCG) and can be used for power generation as most of the countries are using lignite having suitable calorific value (CV) (Table 1). Government of Pakistan is now progressively looking to its indigenous coal reserves not only as a solution to its dependence on imports to fuel to strengthen its economy but also as an alternative fuel of natural gas and power generation in future.

Underground coal gasification has a number of economical and environmental aspects as compared to conventional use of coal (Klimenko, 2009). At present classical mining is the most common technology for the coal extraction irrespective of its well known disadvantages. The preliminary studies show that the extraction of the coal *via* classical mining methods is not economical at Thar as its moisture contents are extremely high (40-50%) (Brockway and Huggins, 1991). Government of Pakistan is now initiating seriously towards clean coal technologies, especially UCG. Underground coal gasification enables us to extract coal reserves that would not normally be mined.

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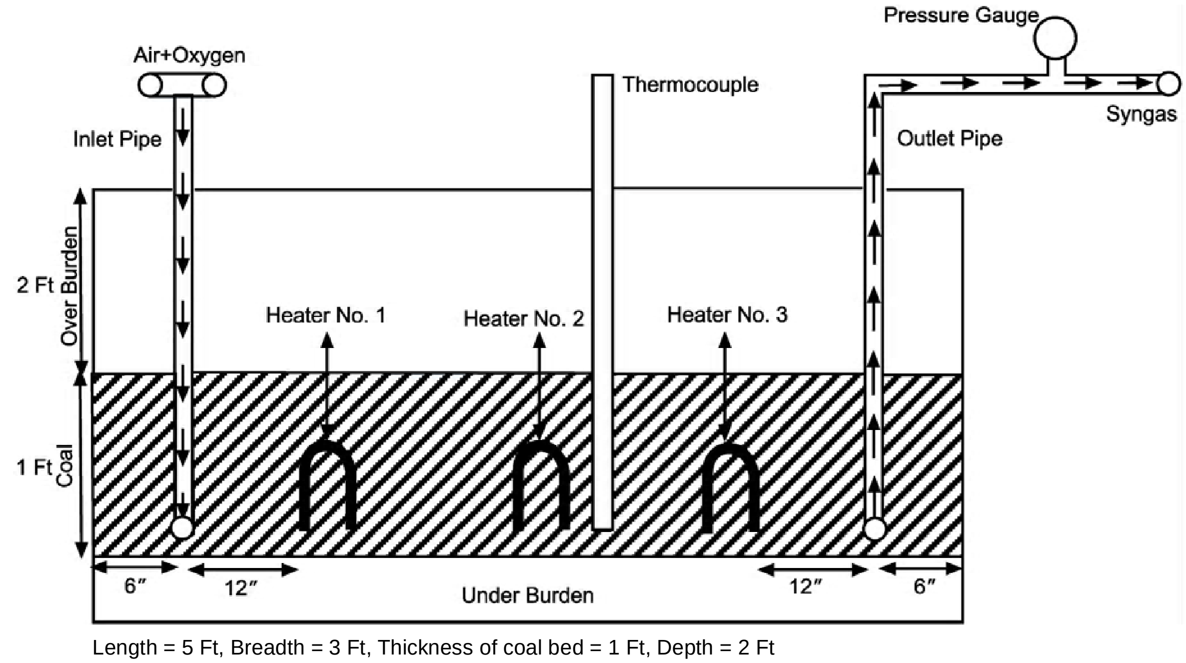
Underground coal gasification is the *in-situ* conversion of coal into product of combustible gases. It is a complex process involving chemical reactions, heat and mass transfer and complex flow dynamics (Guo *et al.*, 2008; GasTech, Inc., 2007). UCG utilizes injection and production wells drilled from the surface and linked together in the coal seam. Once linked, air and / or oxygen are injected. The coal is then ignited in a controlled manner to produce hot, combustible syngas (a mixture of CH_4, CO, CO_2 and H_2) which are captured by the production wells (Fig. 1). The syngas is brought to the surface and cleaned for power generation and liquid hydrocarbon fuel. It can also be used for the generation of other valuable chemical products (Fig. 2).

Chemically, UCG is a complex processes; where following reactions take place:

Combustion of carbon	$C + O_2 \rightarrow CO_2$
Partial oxidation	$C + ½\ O_2 \rightarrow CO$
Oxidation	$C + ½\ O_2 \rightarrow CO_2$
Water gas shift	$C + ½\ H_2O \rightarrow CO_2 + H_2$
Methanation	$CO + ½\ 3H_2 \rightarrow CO_4 + H_2O$
Hydrogenization	$C + 2H_2 \rightarrow CH_4$
Boudouard's reaction	$C + CO_2 \rightarrow 2CO$
Reaction steam-carbon	$C + H_2O \rightarrow CO + H_2$
Loosening of hydrogen	$2H$ (in coal) $\rightarrow H_2$ (gas)



Temperature 200-550 °C Drying pyrolysis	Temperature 200-900 °C Reduction zone	Temperature 900 °C Oxidation zone
Coal $\rightarrow CH_4 + H_2O$	$C \rightarrow H_2O + CO + H_2$	$C + O_2 \rightarrow CO_2$
$CO + CO_2$	$CO_2 + C \rightarrow 2CO$	$C + ½ O_2 \rightarrow CO$
$H_2 + C$	$CO + H_2O \rightleftharpoons CO_2 + H_2$	$C + ½ O_2 \rightarrow CO_2$
Hydrocarbon	$CO + 2H_2 \rightarrow CH_4$	Coal $+ O_2 \rightarrow CO_2 + CO + H_2O$

Fig. 1. Schematic representation of underground gasification of coal.

A number of theoretical and experimental studies concerning UCG have been conducted in many countries, resulting in great progress in this field (GasTech, Inc., 2007; Creedy and Garner, 2004). The aim of the present work is to study the potential of underground coal gasification for Pakistani lignite to exploit Thar coal resources which are either uneconomic to work by conventional extraction by coal mining, or inaccessible due to depth, geology or other mining and safety considerations.

Materials and Methods

Laboratory scale underground coal gasification (UCG) was initiated by Lakhra coal as it is easily available. Thar coal and Lakhra Coal both are Pakistani lignite coals and their physical and chemicals properties are similar to each other. The proximate and ultimate composition and major and minor oxides in Thar lignite resembles to Lakhra coal (Table 2 and 3). Therefore,

Table 1. Comparison of calorific value and power generation in different countries

Country	Calorific value (Btu/lb.)	Total power generation (MW)
India	5, 200	2, 740
Germany	4, 514-11, 054	10, 289
Hungary	3, 035	1, 852
Pakistan Thar Coal	6, 200-11, 000	0.00
South Africa	10, 293	32, 200
China	9, 900	1.95×10^9

Lakhra coal has been selected for UCG experiment. An area of 6′ × 2′ × 3′ has been selected for UCG (Fig. 3a). The coal bed of 1′ thickness having 450 kg of coal has been prepared. An overburden of soil (2′ thickness) was introduced on it. Two adjacent seamless pipes of 6′ length and 1.5″ diameter were inserted vertically into

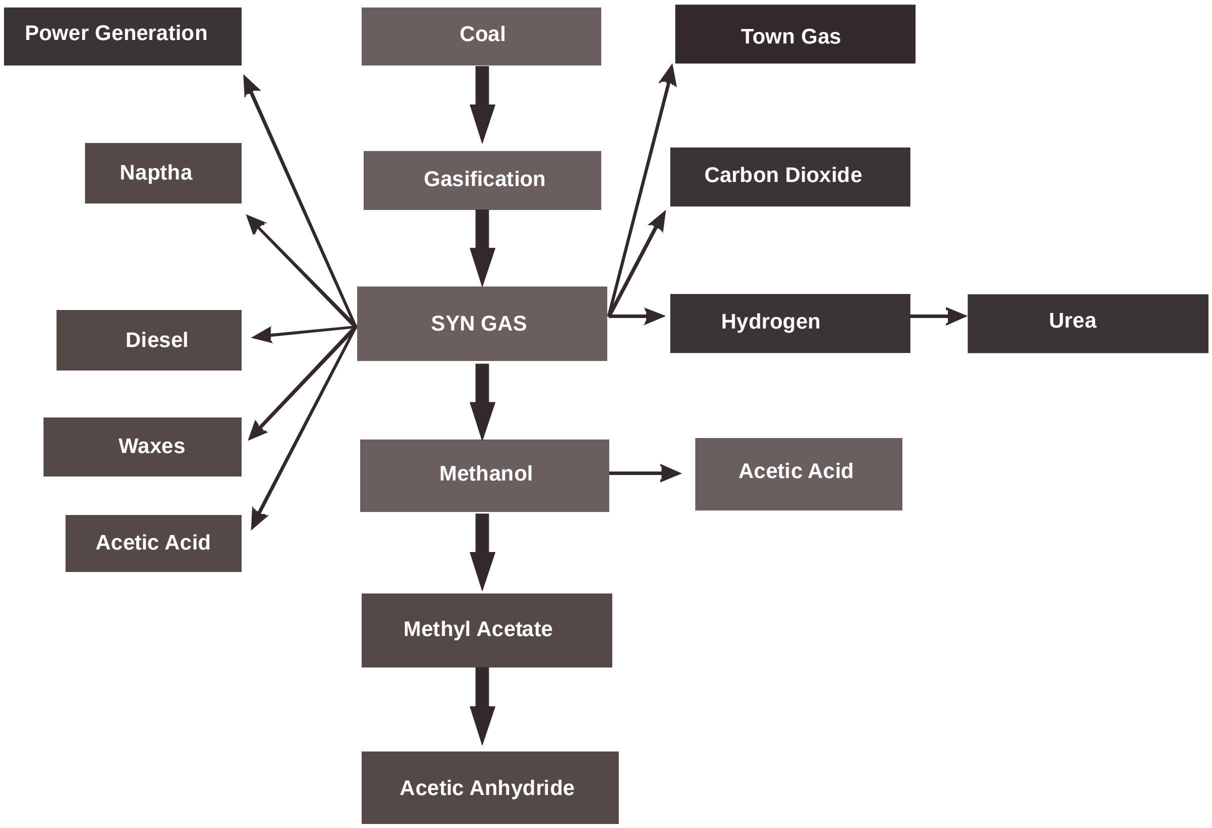


Fig. 2. Refining of syncrude – production of diesel, methanol and petrochemicals.

Table 2. Classification of coal samples

Parameters	Lakhra coal (%)	Thar coal (%)
Proximate composition		
Inherent moisture[b]	25.38	45.24
Volatile matter[a]	30.21	28.38
Ash yield[a]	7.21	5.20
Fixed carbon[a]	37.20	21.18
Ultimate composition		
Carbon[c]	70.24	62.40
Hydrogen[c]	7.98	5.22
Nitrogen[c]	4.29	4.87
Sulphur[a]	3.28	2.07
Oxygen[c]	14.21	25.44
Others		
GCV[e] / Btu/lb	7340.61	6024.38
ASTM Rank	Lignite	Lignite

[a]ar basis = as-received basis; [b]ad basis = as-determined basis; [c]daf basis = dry, ash-free basis; [d]db basis = dry basis; [e]mmf basis = moisture, mineral matter-free basis.

Table 3. Major and minor elements in coal samples

Oxides	Lakhra coal (%)	Thar coal (%)
Major		
SiO_2	35.24	40.21
Al_2O_3	25.28	11.24
Minor		
Fe_2O_3	20.74	18.24
Na_2O	1.50	1.27
K_2O	0.62	0.25
MgO	3.89	4.24
CaO	15.20	13.29
MnO_2	0.01	0.01

the bed as inlet and outlet pipes (Fig. 3b). The connectivity between inlet and outlet pipes was made by passing pressurized oxidants (air 100 psi and oxygen 30-40 psi) into the coal bed. Two electrical heaters of 1000 W were put into the coal bed. Two thermocouples

Fig. 3a. Preparation of coal bed measuring 6' x 3' x 2' filling of coal in bed,insertion of pipes, heaters and thermocouple in bed.

Fig. 3b. Covered bed with installed pipes.

(length 30″, temperature range 0-1800 °C) were inserted near inlet and outlet pipes to measure the temperature continuously inside the bed during operation (Fig. 3c). The coal bed was ignited electrically under controlled conditions and combustion gases evolved were collected through the adjacent outlet pipe and analyzed by Flue Gas Analyzer (Testo t 350 XL, Germany) on the spot. Samples were also collected in cylinders (at 7 psi) and analyzed by gas chromatography (GC) using ASTM D-1945 and D-3588. Components of the gas in the

Fig. 3c. Overview of bed with electrification system.

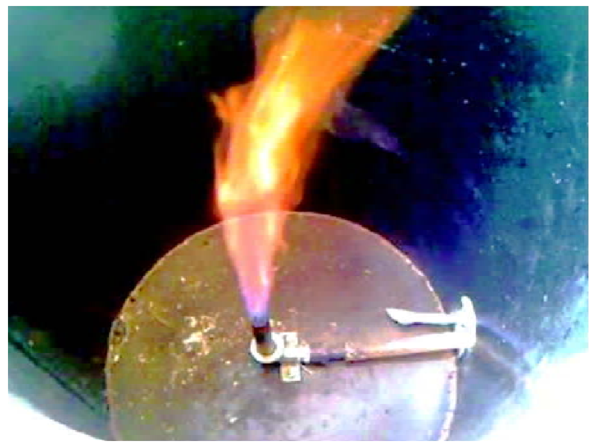


Fig 4. Flame of syngas.

representative scale were physically separated by GC and compared to calibration data contained under identical operating conditions from a reference standard mixture of known composition. The composition of the sample was calculated by comparing the peak areas with the corresponding values obtained with the reference standard.

Results and Discussion

Lakhra coal is of low rank and Tertiary age. It has some important features in relation to its pyrolysis and gasification characteristics. Firstly, as a class of low rank, the oxygen content of Lakhra coal is high and ranges from about 14 wt% (daf). The oxygen exists in a wide variety of functional groups. Carboxylic and phenolic are the most important and highly reactive functional groups present at the surface of Lakhra coal. These functional groups are responsible for the dispersion of some metallic species in the coal (James and Durrani, 1994). They are also involved in various reactions taking place during pyrolysis and affect the properties of pyrolysis products and char (Li, 2007; Schafer, 1991). Secondly; Lakhra coal has a significant amount of Na, Mg, Ca and Fe. These species act as ion exchangeable cations associated with the carboxyl groups forming organic part of the coal or as soluble salts associated with the moisture (Friedmann *et al.*, 2009; Hayashi and Li, 2004; James and Durrani, 1994; Qadeer, 1985). The salt also acts as excellent catalysts for the subsequent char gasification and combustion reactions (Wood and Sancier, 1984). Another significant property of these coals is the significant amount of volatile matter which is responsible for gasification and pyrolysis processes.

In UCG, the use of steam and oxygen is prerequisite in Synthetic Natural Gas production. Coal reacts with steam and oxygen to produce CO, CO_2, H_2, CH_4 and small amounts of other compounds. High permeability and low swelling of coal are desirable properties. Lakhra coal has high permeability as lignites have permeabilities which are about 1000 times higher than the permeabilities of bituminous coals (Schafer, 1991). The natural permeability permits pneumatic linkage without any initial work. In lignite coal natural permeability provides linkage, swelling of coal during gasification plugs the passages available for gas flow. Therefore, Lakhra and Thar coals are suitable for UCG process. After ignition drying and pyrolysis occur at 200-550 °C, reduction of coal occurs in the range of 500-900 °C. While at temperature >900 °C oxidation of coal starts. As the result, coal is converted into gaseous products. The composition of raw gas has been shown in Table 4. Three trial runs were performed to study the composition of syngas. In trial 1, the syngas has been collected in the presence of 20 psi oxygen pressure. The second sample of gas has been collected at the time when the supply of oxygen was stopped after ignition started. In trial 3, 15% coal tar has been mixed in coal to study the effect of coal tar on the composition of syngas. It was observed that the pressure of coal tar in coal has reduced the ignition time and increase the stability of flame. The presence of methane gas was confirmed by ignition test. A flame of blue colour with red/orange tip has been obtained on ignition whose length was 6-12 inch. The flame temperature was 400-600 °C (Fig. 4).

During the experiment syngas was collected in a compressor. The compressor was connected with a gas generator of 2KVA. The generator was connected with a total load of 742 Watt. The details of the total load

Table 4. Analysis of syngas evolved during UCG

S. no.	Parameters	Test result		
		Trial 1 (%)	Trial 2 (%)	Trial 3 (%)
1.	Oxygen	14.02	1.72	2.43
2.	Carbon dioxide	0.09	40.64	21.47
3.	Carbon monoxide	7.02	1.93	3.57
4.	Nitrogen	53.07	48.38	57.63
5.	Methane	4.94	6.06	6.32
6.	Ethane	2.95	0.59	0.54
7.	Propane	1.43	0.52	0.39
8.	iso-butane	Traces	0.758	Traces
9.	*n*-butane	0.377	0.165	0.069
10.	Sulphur dioxide	410 ppm	122 ppm	17 ppm
11.	Hydrogen	102 ppm	6364 ppm	1225 ppm
12.	Nitrogen oxide	1 ppm	35 ppm	2 ppm
13.	Gas gravity	0.90	1.17	0.99
14.	Gross heating value / Btu/ft^3 of dry gas @ 14.65 PSI and 60 °F	410.45 Btu/ft^3	95.95 Btu/ft^3	96.82 Btu/ft^3
15.	Net heating value/ Btu/ft^3 of dry gas @ 14.65 PSI and 60 °F	375.48 Btu/ft^3	88.34 Btu/ft^3	88.67 Btu/ft^3

Fig. 5. View of power generation from syngas.

Table 5. Power generation from Lakhra coal

S. no.	Items	Quantity	Power/ Watt
1.	Electric bulb of 200 Watt	02	400
2.	Electric bulb of 100 Watt	02	200
3.	Tube light	01	20
4.	Energy saver of 24 Watt	01	24
5.	Energy saver of 18 Watt	01	18
6.	Pedestal Fan	01	80
		Total load	742

are shown in Table 5. The results show that syngas generated from Lakhra coal has the potential for power generation (Fig. 5).

Conclusion

Underground gasification of Pakistani lignites has great promise for power and fuel production, While UCG appears to be commercially viable in Pakistan as the country has huge reserves of coal. Owing to high oxygen content, high volatile matter, low swelling index and high permeability of Pakistani lignite, it is suitable for gasification process. The selected coal has been converted into gaseous products via pyrolysis and combustion reaction with the release of considerable amount of syngas. The product gas was found to have the potential to use as a substitute of synthetic natural gas. Syngas is a versatile product that can be utilized in efficient power generation transformed into synthetic gas or liquid fuel or and as chemical feed stock. On the basis of similarities between Lakhra and Thar coal it has been concluded that low grade and inaccessible coal reserves of Thar can not only be utilized for power generation but also as the substitute of natural gas. It gives the aspects of the current understanding that have not been thoroughly studied yet for the utilization of Thar coal in the country.

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