LABORATORY STUDIES ON EFFECT OF VARIOUS OPERATING AND DESIGN PARAMETERS ON PRODUCT GAS COMPOSITION IN THE CONTEXT OF UNDERGROUND COAL GASIFICATION

Sateesh D [1], Ramesh Naidu M [1], Naresh Hanchate[1], Sanjay M Mahajani[1], Anuradda Ganesh[2], Sapru R.K.[3], Sharma R.K.[3], and Preeti Aghalayam[1]*
[1]Department of Chemical Engineering, IIT Bombay, Powai, Mumbai-400076, India
[2]Energy Systems Engineering, IIT Bombay, Powai, Mumbai-400076, India
[3] UCG Group, IRS, ONGC, Chandkheda, Ahmedabad -380005, Gujarat-, India

Summary

Underground coal gasification (UCG) is a technique which permits access to coal which either lies too deep underground, or is otherwise too costly to be exploited using conventional mining techniques. The quality of the UCG product / syn gas strongly depends on the parameters like feed conditions (i.e. steam to oxygen/air ratio, flow rate, etc.) and distance between the injection and production wells. The cavity formed in the coal seam due to consumption of coal acts like a natural chemical reactor of irregular geometry and complex flow patterns. The goal of the present work is to establish a relationship between cavity evolution and various operating and design parameters with the help of laboratory scale experiments. Ultimately, this work would help to obtain the optimum conditions to produce product gas of high calorific value.

Keywords

UCG, Cavity and Syn gas.

Introduction

Coal could be important in meeting world energy demand for many decades into the future. In particular, it is expected that coal will play a significant role during the transition from the world's current dependence on fossil fuels, to cleaner and more sustainable sources of energy that is expected to occur over the coming century[1]. The major draw back for the continued use of coal is its environmental performance. The amount of CO_2 released into the atmosphere per unit of energy produced by burning coal is two-thirds higher than that of natural gas. In addition, coal contains many other elements such as sulphur and nitrogen and traces of heavy metals which have adverse effect on the environment and human health. At the same time, the major advantages of coal over the other fossil fuels are its relative abundance and its low and stable cost. These factors have led to increased interest in Clean Coal Technologies[2]. The UCG process may provide a secure energy supply and reduce green house gas emissions. It is capable of producing commercial quantities of syngas for both the chemical industry and for industrial power generation along with carbon capture and sequestration, which has lead to a growing interest in UCG throughout the world[3].

*preeti@iitb.ac.in

In the first step of the underground coal gasification process, injection and production wells are drilled vertically from the surface to the coal seam. A highly permeable channel is then created between them in order to establish the link between the two wells within the coal seam. Gasification occurs when a mixture of air/oxygen with steam is forced into the coal seam through the injection well and reacts chemically with coal. As the reaction proceeds, a cavity consisting of coal, char, ash, rubble, and void space, is created underground (figure 1). The performance of UCG then mainly depends on geometry, size and flow patterns inside the cavity reactor. The generated product gas is collected through the production well. At the surface, the raw product gas is cleaned and used either as fuel or is converted to chemicals[4].

The underground coal gasification cavity is a result of the interaction of fluid flow, heat transfer, mass transfer, chemical reactions, water influx, thermo mechanical properties of coal, spalling phenomenon and other geological aspects. A number of UCG field trials have been performed during the last forty years[5]. However, it has been possible to extract only a limited amount of field data on cavity growth in a burning coal seam because of the high cost of obtaining such data as well as the difficulty in controlling the operating variables. At the same time, it may not be possible to represent the entire phenomena in laboratory scale experiments. However, the ability to observe the cavity and the relative economy of laboratory scale tests make them attractive[6]. In the present work, a systematic methodology is proposed for laboratory scale experiments to mimic the UCG process, which may provide definite information regarding the trends, in terms of controlling processes, which govern UCG at actual field conditions. The methodology for the laboratory coal block experiments is as follows:

Coal blocks of roughly uniform size were collected at the coal mine and sealed properly to prevent moisture losses. These blocks were shipped to the laboratory where they were cut to the required sizes. Two wells for injection and production are drilled through the coal block from the top surface to the bottom surface vertically. A horizontal channel is therefore created at the bottom of the coal block in order to link the injection and production wells. The five faces of the coal block (except top face) are covered with refractory bricks (figure 2). These refractory bricks and the coal block are sealed with a sealing material (Accoset-50, high temperature cement) to avoid leakage from the reactor. The refractory bricks also ensure minimal heat loss to the surrounding. Initially LPG is passed through the injection well to the coal seam for a short period of time to start the combustion. An electric spark is generated for ignition of the LPG in the channel of the coal block. Once it is ignited the LPG supply is stopped and oxygen is continuously passed through the channel of coal block. The temperature profile is obtained by placing the temperature sensors at different positions within the coal block. Initially pure combustion is carried out for 4 hours with oxygen in order to obtain a sufficient sized cavity. Afterwards steam is introduced into the cavity. Both steam and oxygen are introduced at a high temperature (150-200^{0}C) to perform the gasification reaction.

During steam gasification, it is observed that the temperature in the cavity decreasing slowly. In order to increase the cavity temperature, steam is cut off to the cavity for 20 minutes to get pure combustion. Then, the temperature in the cavity starts to increase and it reaches to original value. After 20 min, again steam is introduced into the cavity for gasification reaction. This procedure[7] is carried out cyclically for 6 hours. After every 10 minutes, product gas samples are collected and analyzed. When the experiment is terminated, the coal block is allowed to cool for 5 hours, and then separated from the refractory bricks. The cavity region alone is covered by a thin aluminum foil and molten wax is poured in. After the wax solidifies, the block is broken in order to obtain the final cavity shape. The final cavity dimensions in four directions (i.e. vertical, transverse, backward and forward) are measured. The cavity volume is calculated by dividing the wax weight by its density. The obtained volume is also confirmed independently through the water displacement technique. The oxygen to steam mole ratio used for gasification experiments is varied from 1**:** 0.5 to 1**:** 4 with different oxygen flow rates (600 ml/min to 1000 ml/min). Three different distances between the wells (12 cm, 16 cm and 20 cm) are chosen to study this effect on the product gas composition.

In the first phase, few experiments are performed to identify the better inlet conditions (steam to oxygen ratio and feed temperature) to obtain the maximum hydrogen mole % in the product gas compositions. Table 1, indicates the percentage of hydrogen, carbon monoxide and oxygen (rest of the components are carbon dioxide and methane) in the product gas. A product gas composition of H_2-23.53 % and CO-5.74 % is demonstrated, which is close to the field trail (Rocky Mountain-1) product gas composition of H_2-27.3 % and CO-6.4 %. In the next phase, it is planned to study the effect of various parameters (i.e. entering conditions, cavity shape, product gas composition etc.) for the gasification in the laboratory scale UCG reactor.

The major goal of performing systematic laboratory scale experiments on the chosen lignite coal samples is to study how cavity growth and the influence by various operating and design parameters. The product gas is also analyzed to obtain the effect of these parameters on process performance. Effect of distance between the wells, steam to oxygen/air ratio, feed gas flow rate and feed temperature on both product gas composition and cavity evolution will be presented in detail. The final cavity dimensions in three directions and the corresponding cavity volumes will be obtained for the given lignite coal blocks by varying the design and operating parameters. The information regarding the relationship between various operating parameters and cavity volume / three dimensional shapes will be presented. Ultimately, this work may be the basis for evaluating optimum conditions and to determine the economic feasibility of a given coal for underground coal gasification (UCG) process.

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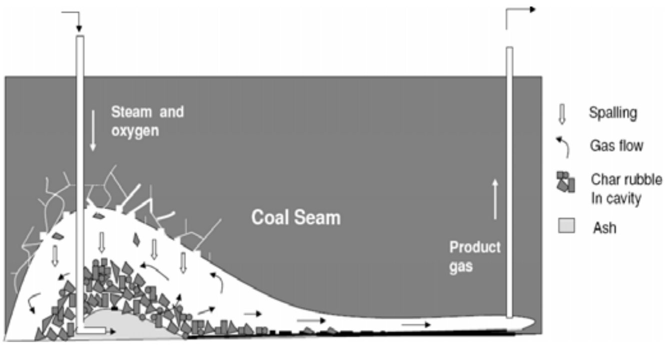

Figure 1: Schematic diagram of the UCG process

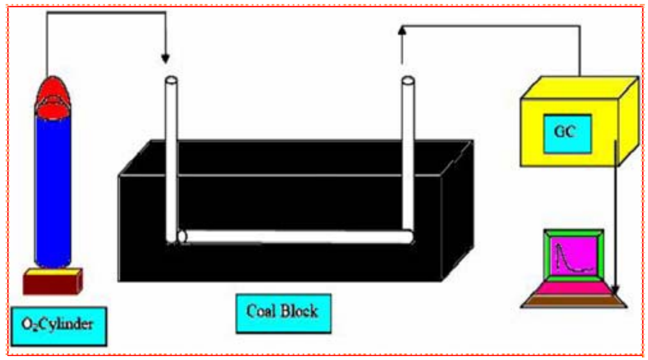

Figure 2: Schematic diagram of Laboratory scale UCG reactor experimental set-up

Table 1: Operating conditions and product gas compositions

DBW (cm)	O2 Flow rate (ml/min)	Steam temperature	O_2 :Steam	H_2 %	CO %	O_2 %
20	600	400 ^{0}C	1 : 0.5	16.02	5.25	13.04
			1 : 0.6	18.34	5.08	15.94
			1 : .75	19.56	5.51	10.52
			1 : 1	14.36	5.51	12.12
18	900	300 ^{0}C	1 : .77	23.53	5.74	9.1
			1 : 1	19.74	4.86	14.47
			1 : 1.5	13.09	3.65	31.25
16	1000	250 ^{0}C	1 : 1	3.65	5.33	10.66
			1 : 1.5	7.7	4.9	15.53
			1 : 2	3.43	4.75	14.05
			1 : 2.5	11.52	4.51	37.31
12	800	200 ^{0}C	1:2.5	13.26	6.12	5.84
			1:3	16.14	6.2	7.12
			1:3.5	17.48	7.32	8.31
			1:4	16.35	5.92	8.58