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Comparison between two types of Indian coals for the feasibility of Underground Coal Gasification through laboratory scale experiments

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HIGHLIGHTS

- A laboratory scale methodology for assess the coal for its feasibility for UCG.
- A comparative study of Indian lignite and hard coal is conducted.
- Gas calorific value of lignite is 170 kJ/mol and that of hard coal is 69 kJ/mol.
- Two coals differ significantly in their spalling behavior.
- Lignite char is found to be ten times more reactive than hard coal char.

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ABSTRACT

Underground Coal Gasification (UCG) process is studied through systematic laboratory scale experiments. Our earlier published work (Daggupati et al., 2011) demonstrated the various features of the Indian lignite coal in context of its applicability for UCG. In the present work, we study a hard Indian coal, with low volatile matter and moisture content. These results are compared with that of lignite type soft Indian coal, which has relatively high volatile matter and moisture content. The syn-gas produced from hard coal has a calorific value of 69 kJ/mol whereas the syn-gas from lignite coal has a higher calorific value of 170 kJ/mol, under similar conditions, in the laboratory experiments that mimic UCG process. Since UCG is a complex process involving different phenomena like spalling, gas–solid reactions of char and diffusion of gas in the char layer, separate studies on these aspects are required to explain the difference in the behaviors of these two coals in UCG. Spalling tendencies of these two coals are studied qualitatively by performing separate sets of experiments and the findings are used to explain the laboratory scale UCG results. The spalling experiments show that the hard coal has no tendency to spall, but lignite coal spalls, especially under high temperature and reactive atmosphere. The reactivity of the respective chars is studied separately using Thermo Gravimetric Analyzer. It is found that the char produced from lignite coal has higher reactivity of around ten times than the char produced from the hard coal. The paper thus presents a simple laboratory method to evaluate the feasibility of a given coal for UCG with theoretical analysis of the results obtained.

1. Introduction

Underground Coal Gasification (UCG) is a technology applied to convert the coal present in underground coal seams directly to combustible product gas without mining it in its original solid form. The technology of UCG is aimed at exploitation of primarily those coal deposits, which are not amenable to conventional mining [1]. It involves many physical processes like drying, pyrolysis and spalling and chemical reactions like combustion and gasification. A schematic of the UCG process is given in Fig. 1.

During the process of UCG, a cavity is formed in the coal seam due to the consumption of coal by chemical reactions [2]. The coal matrix present at the roof of the UCG cavity may develop fractures due to thermal stresses and coal pieces may fall on the floor of the cavity. This process is called as spalling [3]. The possible advantage of spalling in UCG is that it forms a permeable bed of coal particles offering relatively large surface area for chemical reactions to hap-

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Nomenclature

X	conversion	L_0	pore length per unit volume at $t = 0$
t	time	ε	porosity at $t = 0$
k_0	frequency factor	S_0	surface area per unit volume at $t = 0$
E	activation energy	a	heating rate
R	gas constant		
T	temperature		
ψ	structural parameter		

pen. The cracks developed on the char layer, both at the roof and also in the spalled coal blocks, determine the rate of diffusion of reactive gas molecules to the char matrix by offering a lesser resistance path. If numerous microcracks are developed on the char layer, it becomes more porous and reactive. The chemical reaction rates of the char produced from different coals are likely to vary due to physical reasons like char morphology or the chemical reasons like the presence of catalytic minerals in the ash. A detailed procedure of UCG may be found elsewhere [4].

In our earlier laboratory scale experiments on lignite coal block, it was observed that a product gas of calorific value as high as 170 kJ/mol could be produced [4]. A comparative study on two types of coal for UCG exists in the literature and it has been demonstrated that the calorific value of product gas in UCG depends on coal properties [5]. In the present work, laboratory scale experiments on hard Indian coal are performed. The product gas calorific value of hard coal is compared with that of lignite type coal. Then different physical and chemical processes related to UCG such as coal spalling, development of porous char structure and reaction kinetics are studied separately for the two coals and the results are used to explain the difference in product gas calorific values of two coals.

2. Experimental work

The experimental work presented here is divided in several parts viz. laboratory scale micro-UCG experiments, spalling experiments, study on crack development in coal monolith and reaction kinetics.

2.1. Micro-UCG experiments

The laboratory scale experiments on coal blocks are conducted to mimic the UCG process. These are called as Micro-UCG experiments due to their peculiarity of very short length scale compared to actual UCG process. A schematic of the experimental setup is given in Fig. 2.

The experimental procedure starts with collection and preparation of a coal block. The sample coal blocks are selected from coal mines with the cutting plane parallel to the bedding plane. The sample is preserved at its original condition by wrapping it in wetted cotton packing. The coal block is cut into required size of approximately $350 \times 220 \times 130$ mm. Two vertical wells are drilled with a gap of approximately 220 mm. One is injection well and the other is production well. These two wells are interconnected by a horizontal channel at the base of the coal block. The product gas is sampled from the production well at regular time intervals and is analyzed in Gas Chromatograph.

The experiment is conducted in three phases such as ignition, combustion and gasification. In the ignition phase, the coal present at the base of injection well is ignited with a combustible mixture of liquefied petroleum gas (LPG) and oxygen. After igniting the coal, LPG is cut off and burning of coal is continued with oxygen. We call this as combustion phase. After attaining sufficient temperature in the cavity for the endothermic gasification reaction to sustain, steam is introduced at the inlet stream to initiate gasification.

2.2. Spalling experiments

The spalling behavior of a coal is studied independently by heating the bottom face of coal block first in inert and then in reactive atmospheres. The schematic of the experimental setup is shown in Fig. 3.

Here, a rectangular channel for the gas flow is made out of refractory bricks with inlet and outlet pipe connections to it. The top face of the channel is open and the bottom of the channel has a plate type electric heater with a capacity to go up to 1000 °C. A coal block is cut into specified dimensions and placed over the refractory bricks to close the channel from the top. The gap between the coal block bottom face and the heater plate is approximately 15 mm. The sides of the coal block are sealed with thermally stable alumina cement to prevent gas leakage. The experiment is conducted by heating the coal block under inert and reactive atmospheres, separately. At the end of the experiment, the coal block is cooled and removed. The channel is examined for the presence of spalled particles, if any.

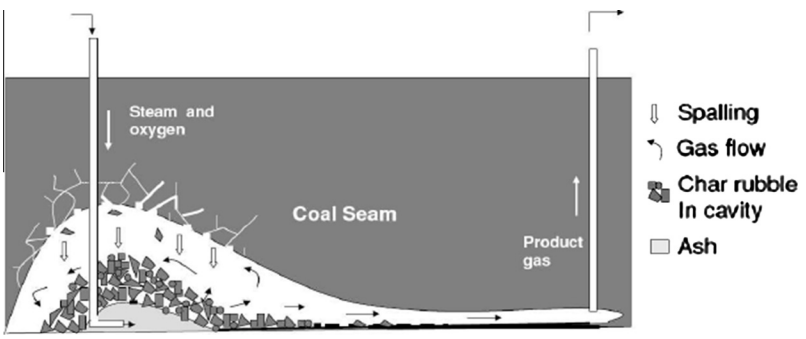

Fig. 1. Schematic of UCG process [4].