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Experimental study on the impact of reactant gas pressure in the conversion of coal char to combustible gas products in the context of Underground Coal Gasification

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HIGHLIGHTS

- Optimum gasification conditions were determined for the bituminous coal.
- Pressure enhances the gasification rate and hence the gasification efficiency.
- There is an optimum operation pressure which produces the best heating value of the product gas.
- Carbon conversion does not seem to be affected significantly by the type of coal.
- The shrinking core model predicts fairly well the reaction of char with CO_2 and steam at 0.1 MPa.

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ABSTRACT

This paper describes an experimental investigation to determine the impact of pressurised reactor conditions within the reduction zone of a gasification process employing a semi-batch reactor with a bituminous coal. The conditions examined with this bespoke pressurised rig were designed to be representative of an Underground Coal Gasification (UCG) process, at pressures up to 3.0 MPa and temperatures up to 900 °C; coal samples were approximately 36 g per test. Current published literature suggests that one of the key controlling factors in the conversion and yield within such processes is the behaviour of the pyrolysed coal (char) in the reduction zone of the UCG cavity. This was achieved by using carbon dioxide and steam as the primary reductants with char derived from bituminous coal at a variety of pressure and temperature levels, plus at a range of relative H_2O/CO_2 proportions. The composition of the resulting product gas was measured and subsequently used to calculate cold gas efficiency and carbon conversion (during 90 min at steady state). A shrinking core model was then employed to determine the activation energy and pre-exponential factor under these conditions. The results were then used to extrapolate the contribution of the reduction zone in published research including UCG field trials where discrete analysis of the zones within the gasification cavity was not possible. It was shown that pressure increases the reduction–gasification process of the char in terms of carbon conversion, cold gas efficiency and heating value of the product gas. Under the conditions evaluated herein, optimum gasification conditions for the bituminous coal were determined as 1.65 MPa at H_2O/CO_2 ratio of 2:1 by mass at 900 °C which produced a syngas with a composition of 17.4% CO, 3% CH_4, 42.1% H_2 and LHV of 7.8 MJ/N m^3.

1. Introduction

Underground Coal Gasification (UCG) is the process by which unmineable coal resources are converted in situ into a combustible gas. Pressurised oxidants such as steam and air or oxygen are injected into the coal seam in order to react with coal and form a product gas. The main gases produced are H_2, CO, CH_4 and CO_2, in proportions depending on temperature, pressure and the composition of the reactant gases injected [1–3]. Although it can be challenging to accurately measure or reproduce these conditions in a reliable fashion, it is generally believed that at high enough temperatures, free oxygen reacts completely with the solid carbon within a relatively short distance from the injection point. The heat evolved acts to pyrolyse the adjacent coal and the char formed

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then reacts with carbon dioxide, steam or other gases formed by combustion and pyrolysis [4–6]. The key substance, and hence driver of the net gasification process under these conditions is therefore CO_2 which is produced during the oxidation zone [5,7,8]. At the reduction zone CO_2 and steam, which is either introduced deliberately into the cavity or is flowing into the cavity from the oxidation of the surrounding strata, reacts with char and produces around 60% of the total gas product (by volume) during the UCG process. The remaining 40% is produced during the devolatilisation phase, although this is highly dependent on reactor condition, the type of coal and the gaseous reactants [4].

Fig. 1 illustrates the three reaction zones of a reacting channel during a UCG process, which are the oxidation, reduction and pyrolysis zones. During the oxidation zone, as the coal is consumed more coal falls into the growing void, which creates a high coal surface area available for reaction and permits contact between the hot gases and the coal [5,7]. This area is the final reduction zone which converts excess CO_2 to CO and is responsible for the uniform quality of the product gas. Measurement of the upstream gas composition in the oxidation zone has shown comparatively low heating values which demonstrate that the reactions in the oxidation zone do not have such a significant effect on the product gas composition [8,9]. Finally the pyrolysis zone is where the devolatilisation of the coal takes place, forming char that contains active sites for subsequent gas–solid reactions.

In this work some of the key parameters controlling in situ UCG via a laboratory scale reactor are studied; hence the aim of this research is to demonstrate the effect of the reduction zone reactions at a variety of temperatures and compare this impact to previously published work on UCG field trials. Gasification conditions were established so as to simulate the reduction zone of the UCG process, as this has been identified as a primary controlling factor in the overall mass and energy balance in UCG processes. The effect of the main operating parameters, which included pressure, temperature, flow rates and composition of gaseous reactants were studied. The outputs from the experiments included carbon conversion, cold gas efficiency (CGE) and lower heating value (LHV) of the product gas, which can be used to quantify the effective 'efficiency' of the reduction zone of a UCG process and the suitability of the coal seam for a UCG project. In comparable work by other authors, Chapell (1998) theoretically expressed the efficiency of the gasification process by defining the autothermal chemical equilibrium (ACE) which is a condition at which the heating value of the product gas and the conversion efficiency of the gasified coal (chemical energy of product gas/chemical energy of gasified coal) is a maximum [10]. ACE is identical to CGE within the context of the research undertaken in this paper.

2. Experimental

2.1. Experimental apparatus

Experiments were conducted with a bespoke high pressure, high temperature tubular rig which is shown in Fig. 2 and as a schematic in Fig. 3, and operated at pressures up to 5.0 MPa and

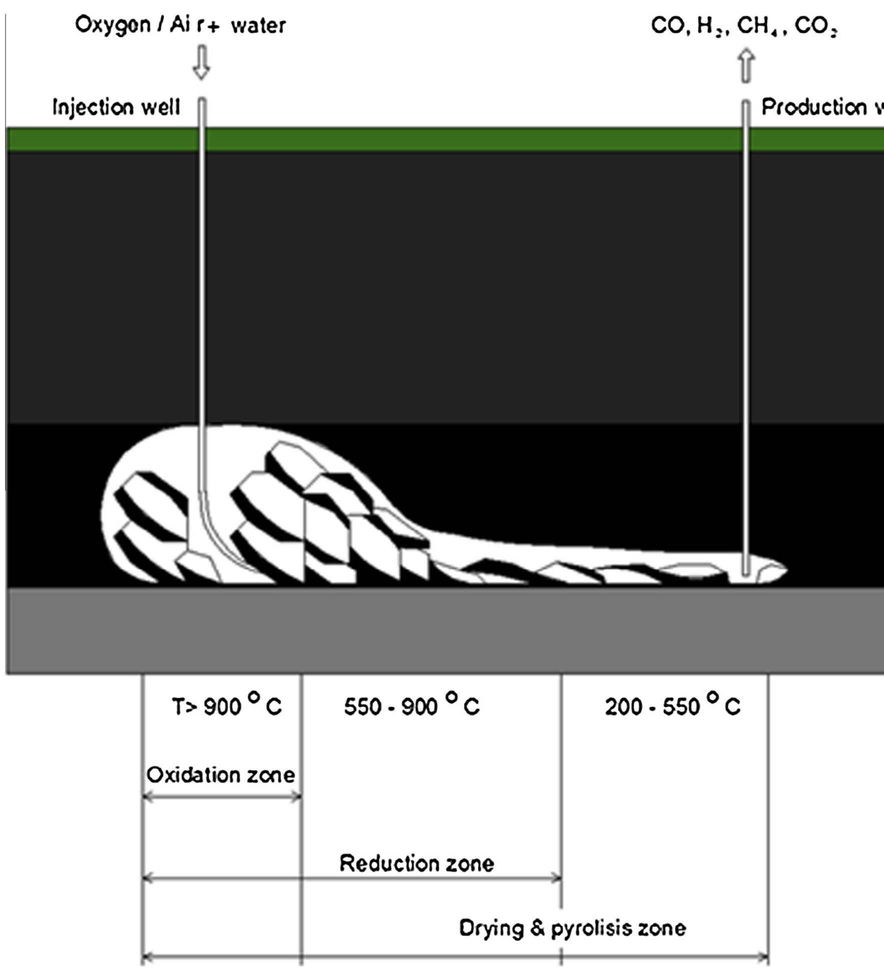

Fig. 1. The three reaction zones of an underground coal gasification channel.