Available online at www.sciencedirect.com
ScienceDirect
Fuel 86 (2007) 194–202
FUEL
www.fuelfirst.com

Experimental investigation of role of steam in entrained flow coal gasification

Nenad Crnomarkovic, Branislav Repic, Rastko Mladenovic *, Olivera Neskovic, Miomir Veljkovic

Institute of Nuclear Sciences – Vinca, Laboratory for Thermal Engineering and Energy, P.O. Box 522, 11001 Belgrade, Serbia and Montenegro

Received 13 January 2006; received in revised form 16 June 2006; accepted 21 June 2006
Available online 26 July 2006

Abstract

Experimental investigations of the influence of excess oxygen coefficient, H_2O/coal mass ratio using high-temperature steam, mean mass diameter of pulverized coal and coal size fraction on basic characteristics of coal gasification were performed. Experiments were carried out on a laboratory scale (0.09 m i.d. × 1.5 m high) coal gasification apparatus with lignite type of coal. Influence of steam was realized through comparison of results obtained from experiments with ($H_2O/coal = 0.287\ kg\ kg^{-1}$) and without steam addition ($H_2O/coal = 0.024\ kg\ kg^{-1}$). High values of carbon conversion, obtained both for finely ground and for coarse pulverized coal points to the easiness of lignite gasification, i.e. to its high suitability for gasification.

Keywords: Coal gasification; Entrained flow; Steam

1. Introduction

Gasification is a coal conversion process by which combustible gas from coal is produced. Gas obtained by coal gasification can be used in many ways: for electricity production (which is probably the most important use), in chemical industry for petrol, methanol and ammonia synthesis, for ore reduction, as an industrial fuel, as a town gas for domestic uses, for residential heating etc. According to predictions made by Longwell et al. [1], systems of electricity production which use coal gasification will become competitive with other technologies of electricity production after 2006. The main advantage of these systems, so-called integrated gasification combined cycle systems, when compared to conventional plants with pulverized coal (PC) combustion, is easier and more efficient removal of sulfur and nitrogen oxides precursors, as well as easier removal of CO_2. Ash particles emission is lower as well, and thermal efficiency is higher by about 5–10%.

Coal gasification processes are known, well studied and described in literature [2–4]. There are three basic reactor types which are employed in the gasifier design: fixed bed, fluidized bed and the entrained flow. In the investigations described in this study, entrained flow coal gasification has been chosen as a promising way of gas production, due to its high coal throughput, insensitivity to coal type and its simplicity in design and technology [5].

Entrained flow coal gasification process has been widely investigated experimentally in small-scale gasifiers, and with different types of coals [5–8]. Small-scale entrained flow coal gasifiers are suitable for establishing a relationship between laboratory and commercial gasifiers. Lee et al. [8] show that it is difficult to generalize the gasification characteristics for coals of different properties because various reactions take place in coal gasification. On the other hand, some investigations state [5–7] that carbon conversion is essentially independent of coal type. One of the main reasons for this study is to examine the performance

* Corresponding author. Tel.: +381 11 2458 222x217/+381 64 2471665 (mobile); fax: +381 11 2453 670.
E-mail address: rastkom@vin.bg.ac.yu (R. Mladenovic).

0016-2361/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.fuel.2006.06.015

of Serbian lignites under entrained flow gasification conditions. These fuels have high moisture and ash contents, which will affect their performance. The data obtained can be used to validate models of entrained flow gasifiers using lignite.

The main goals of the investigations in this study were experimental assessment of the gasification of indigenous lignite in an entrained flow gasifier, and determination of the influence of main parameters. The following investigations were performed: the influence of excess oxygen coefficient (λ); the influence of mean mass diameter of PC; the influence of H_2O/coal mass ratio using high-temperature steam, and the influence of coal size fraction on basic characteristics of PC gasification.

2. Basic reactions of coal gasification

Coal gasification essentially comprises of two successive processes: pyrolysis (between 573 and 773 K) and char gasification [4,9]. Basic reactions of coal gasification processes can be divided into two groups: exothermic and endothermic reactions. Main exothermic reactions are reactions of oxygen with carbon and hydrogen from coal, and the water gas shift reaction. Main endothermic reactions are reactions of CO_2 reduction (Boudouard's reaction) and the water gas reaction.

Reactions of oxygen with carbon and hydrogen from coal supply heat which is necessary for endothermic reactions [2]:

$$C + O_2 = CO_2 \quad \Delta H^0_{298} = -393.51\ \mathrm{kJ\,mol^{-1}} \tag{1}$$

$$2H_2 + O_2 = 2H_2O \quad \Delta H^0_{298} = -285.84\ \mathrm{kJ\,mol^{-1}} \tag{2}$$

These reactions proceed to complete consumption of oxygen. Water gas shift reaction is a slightly exothermic reaction:

$$H_2O + CO = H_2 + CO_2 \quad \Delta H^0_{298} = -41.17\ \mathrm{kJ\,mol^{-1}} \tag{3}$$

Reaction of CO_2 with carbon is an endothermic reaction:

$$C + CO_2 = 2CO \quad \Delta H^0_{298} = 172.5\ \mathrm{kJ\,mol^{-1}} \tag{4}$$

The most intensive change of concentrations occurs in the temperature range from 700 to 1200 K. Above the temperature of 1200 K, the concentration of CO_2 is almost 0% (vol%), and the concentration of CO is almost 100% (vol%). Water gas reaction is an endothermic reaction:

$$C + H_2O = H_2 + CO \quad \Delta H^0_{298} = 131.3\ \mathrm{kJ\,mol^{-1}} \tag{5}$$

The most intensive decomposition of steam occurs in the temperature range from 600 to 1100 K. Above the temperature of 1100 K, the concentration of steam is almost 0% (vol%), while hydrogen and CO concentrations are equal and approach 50% (vol%).

Sebastian [10] studied the influence of steam temperature on entrained coal gasification products. The results were obtained by translation of operating results from experimental to adiabatic conditions and assuming exit gas temperature of 1255 K. The H_2O/coal mass ratio was varied from 0 to 2.5 kg kg^{-1} of dry, ash-free coal. It was reported that the steam injected must be superheated to minimum temperature of about 1255 K to act as a heat-transfer medium. Any increase in H_2O/coal ratio below that temperature would decrease the percentage of carbon gasified and thus the yield of synthesis gas, and increase the oxygen requirement. Azuhata et al. [5] performed experiments on entrained coal gasification, in which two H_2O/coal ratios were used: 0.03 and 0.32 kg kg^{-1}. Partial coal combustion was achieved in premixed flame. Although steam was preheated up to 590 K, the production of hydrogen was hardly affected by steam injection, but lower H_2O/coal ratio yielded higher levels of CO and lower levels of CO_2.

3. Apparatus, coal properties and experimental procedure

3.1. Experimental facility

Experiments were carried out on a laboratory scale (0.09 m i.d. × 1.5 m high) down-fired coal gasification apparatus (Fig. 1). This reactor was built for the purposes of a project (research programme) started in agreement with the Electric Power Industry of Serbia, with the aim to determine the gasification properties of Serbian lignites. In the later phase, the project was supported by the Ministry of Science of Serbia. After the research programme was completed, all research on this reactor terminated.

The burner (3), through which oxygen, air, propane–butane (PB) and PC are introduced, is placed on top of the reactor [11]. Pulverized coal enters the reactor along the axis together with the carrying air. The oxygen for completion of PB combustion is introduced together with the air in the primary stream that surrounds the PC stream. The pressure in the reactor was atmospheric. Using a screw type coal feeder with a capacity of 3–6 kg/h, coal was introduced into the reactor along the reactor axis. The oxygen needed for partial coal combustion and complete hydrogen combustion was injected through the primary stream. Hydrogen was injected through the secondary stream, surrounding the primary stream. Partial coal combustion and complete hydrogen combustion were performed in diffusion flame.

The combustion products are cooled in the scrubber with water. Solid products were collected by filtering of the scrubber water, and the gaseous products were collected in glass sampling vessels (8). The concentrations of major gas species in dry product gas, i.e. CO, CO_2, H_2, NH_3, H_2S, O_2 and N_2, were measured with mass spectrometer, which could not differentiate CO from N_2, due to a small difference of molecular masses.

3.2. Coal sample

Coal used in experiments was domestic lignite Kolubara pit D. Coal was ground in a laboratory mill as fine and