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Effect of the type of gasifying agent on gas composition in a bubbling fluidized bed reactor

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A B S T R A C T

It is commonly accepted that gasification of coal has a high potential for a more sustainable and clean way of coal utilization. In recent years, research and development in coal gasification areas are mainly focused on the synthetic raw gas production, raw gas cleaning and, utilization of synthesis gas for different areas such as electricity, liquid fuels and chemicals productions within the concept of poly-generation applications. The most important parameter in the design phase of the gasification process is the quality of the synthetic raw gas that depends on various parameters such as gasifier reactor itself, type of gasification agent and operational conditions. In this work, coal gasification has been investigated in a laboratory scale atmospheric pressure bubbling fluidized bed reactor, with a focus on the influence of the gasification agents on the gas composition in the synthesis raw gas. Several tests were performed at continuous coal feeding of several kg/h. Gas quality (contents in H_2, CO, CO_2, CH_4, O_2) was analyzed by using online gas analyzer through experiments. Coal was crushed to a size below 1 mm. It was found that the gas produced through experiments had a maximum energy content of 5.28 MJ/Nm^3 at a bed temperature of approximately 800 °C, with the equivalence ratio at 0.23 based on air as a gasification agent for the coal feedstock. Furthermore, with the addition of steam, the yield of hydrogen increases in the synthesis gas with respect to the water–gas shift reaction. It was also found that the gas produced through experiments had a maximum energy content of 9.21 MJ/Nm^3 at a bed temperature range of approximately 800–950 °C, with the equivalence ratio at 0.21 based on steam and oxygen mixtures as gasification agents for the coal feedstock. The influence of gasification agents, operational conditions of gasifier, etc. on the quality of synthetic raw gas, gas production efficiency of gasifier and coal conversion ratio are discussed in details.

1. Introduction

The oil crisis and global environmental problems have become critical challenge worldwide; therefore, more and more attention has been paid to the clean coal technologies, among which the coal gasification is one of the critical ones for efficient utilization of coal. Compared to the coal combustion, there is a lower reaction rate in coal gasification process.

Coal gasification is becoming an attractive alternative for power generation since it offers higher efficiency and improved environmental performance than conventional pulverized fuel technology [1]. Various types of gasifiers such as moving bed, entrained flow, and fluidized beds have been employed by industry, but intensive research activities for technology development and improvement are still ongoing. Fluidized bed reactors are much more suitable for low rank coal having mostly high ash, high sulfur and high moisture. Therefore, fluidized bed gasifiers have the potential advantage that low rank coals can be processed more efficiently than in conventional pulverized coal boilers. The higher efficiency that coal gasification offers could be used as a strategy for carbon abatement in the future. A potential disadvantage of

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fluidized bed coal gasification is low carbon conversion in comparison to other types of gasifiers. This is due to its low operating temperature (900–1050 °C) and rapid loss of reactivity [1,2].

Gasification process has been used for different application areas such as power generation, gaseous and liquid fuel production or chemical production. But the production of gas having high calorific value, high H_2 and CO content together with high fuel conversion ratio and gas efficiency are the main targets to be realized in the design and operation. In the recent years, several studies have been performed to validate the design and to optimize the operation conditions of coal and/or biomass gasification processes.

The fluidized bed gasifier is one of widely applied technologies, because a longer residence time, uniform temperature distribution, high mass and heat transfer rates could be achieved in such kind of reactor. So, different studies on coal and/or biomass gasification in fluidized beds have been realized. Tomeczek et al. [3] performed an experimental study on coal gasification under the gasification medium of air and steam–air mixtures at atmospheric pressure. They reported that the gas heating values varied between 2.9 and 3.5 MJ/m^3 using air and 4.1–4.5 MJ/m^3 using air–steam mixtures. Watkinson et al. [4] realized some experiments with different coals in a fluidized bed gasifier under the gasification medium of air and steam. They found that the heating values of gas varied between 1.6 and 4.2 MJ/m^3. Ocampoa et al. [5] made an experimental study for the gasification of Titiribi coal in a pilot scale fluidized bed reactor at atmospheric pressure with air and steam mixtures and they obtained the heating value of gas as 3.3 MJ/m^3. Karimipour et al. [6] performed a series of experiments to study the effect of three operating factors, namely, coal feedrate, coal particle size, and steam/O_2 ratio, and their interactions on the quality of syngas produced from fluidized bed gasification of lignite coal. They found that the higher heating value of syngas was between 3.77 and 4.21 MJ/m^3. Karatas et al. [7] carried out gasification tests by using a laboratory scale bubbling fluidized bed gasifier under air atmosphere. They investigated the effects of equivalence ratio, coal type and calcined dolomite on gas quality and properties. They found that the lower heating value syngas for different coals under the test conditions were between 4.36 and 6.16 MJ/Nm^3. Kim et al. [8] performed an experimental study on the gasification of a sub-bituminous coal in a down-flow reactor. When the steam/coal ratio increased from 0.23 to 0.86, they observed a decrease in the heating value of product gas from 9.0 to 6.4 MJ/m^3 in the gasification region due to reduction of combustible gas. A similar trend was reported for bituminous and anthracite coals by Zhou [9] but the higher heating values of gas were between 2.2 and 3.4 MJ/Nm^3.

In addition, different studies have also been performed in fluidized bed gasifier by using different coal, biomass and co-gasification of different feedstocks [10–18]. A comprehensive comparison data for some reported result was given by Taba et al. [19]. The experimental studies are mostly based on the gasification medium of air, or air/steam condition. However, few researchers reported the coal gasification in a fluidized bed under O_2/steam atmosphere.

In this paper, the results of two different gasification agents obtained in a laboratory scale bubbling fluidized bed gasifier are presented. The activities have been performed within an ongoing project, supported by TUBITAK under the frame of 1007 Research Grant Program “Liquid Fuel Production from Biomass and Coal Blends”. In the project, it is aimed to develop the technologies on liquid fuel production from coal and biomass blends and demonstrate the results on a pilot scale integrated system. Within this frame, R&D activities on the related technologies such as gasification, gas cleaning, gas separation and conditioning and Fischer-Tropsch synthesis and conversion of syngas into liquid fuels are ongoing within the projects.

The performance of gasifier depends on many design and operational parameters such as fuel type, reaction temperature, pressure, gasification agents etc. This paper presents the results obtained in the gasification of Turkish Soma lignite in a fluidized bed gasifier at atmospheric pressure with the presence of air or oxygen/steam mixture to explore the effects of operating parameters on gasification performance and to evaluate the efficiency of raw gas production for gasification process.

2. Methodology

2.1. Coal feedstock and its characterization

The coal used in the current study was lignite obtained from Soma, a county of the Manisa Province in the Aegean region of Turkey. The raw feed containing high amount of moisture was air dried. The dried feed was then crashed. The ultimate and proximate analyses of coal tested are presented in Table 1.

2.2. Experimental facility

A schematic diagram of the lab-scale bubbling fluidized-bed gasifier used in the experiments appears in Fig. 1. The reactor is split into two sections as shown in Fig. 2: a bed section and a freeboard section. The fluidized bed reactor is formed by two vertical stainless steel tubes

Table 1
Proximate and ultimate analysis of coal (at original basis).

Proximate analysis		
Moisture	wt.%	13.75
Ash	wt.%	24.61
Volatile	wt.%	34.52
Fixed carbon	wt.%	27.12
Lower heating value	kJ/kg	15,786.23
Ultimate analysis		
Carbon	wt.%	48.4
Hydrogen	wt.%	2.84
Oxygen	wt.%	11.5
Nitrogen	wt.%	0.94
Sulfur	wt.%	1.16