Journal of the Energy Institute xxx (2017) 1–10

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Partial slagging coal gasifier operational performance and product characteristics for energy sustainability in an integrated gasification combined cycle system

Jin Wook Lee [a], Seung Jong Lee [a], Yousuf Jamal [a, b], Yongseung Yun [a, *]

[a] Institute for Advanced Engineering, 175-28, Goan-ro, 51 Beon-gil, Baegam-myeon, Cheoin-gu, Yongin, Gyeonggi-do, 449-863, Republic of Korea
[b] Institute of Environmental Sciences and Engineering (IESE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST), H-12, Islamabad, 44000, Pakistan

A R T I C L E I N F O

Article history:
Received 23 November 2016
Received in revised form
7 May 2017
Accepted 10 May 2017
Available online xxx

Keywords:
Partial slagging
Entrained-bed gasifier
Carbon conversion
Cold-gas efficiency
Syngas composition

A B S T R A C T

Operational performance of two ton/day coal partial slagging entrained-bed gasifier has been investigated. Coal to syngas conversion under operating temperature (1100–1300 °C), pressure (19.7–20.4 bar) and oxygen to coal ratio of 0.70 produced syngas at a flow rate of 177.5 Nm^3/h. Composition of produced syngas was; CO 38–40 vol%, H_2 22–23 vol%, CO_2 7–8 vol%, and CH_4 1.0–1.5 vol%. Carbon conversion and cold gas efficiency after one pass through operation were found to be 92.81% and 73.83% respectively. Fly ash fines produced were high in carbon content and acidic oxides than the bottom slag. Non-metal leaching nature of bottom slag was confirmed with ICP analysis. Based on the results, an industrial symbiosis can be established by recycling and reusing high carbon content fly ash fines in the gasifier. The same can be sold to other industries as a quality energy fuel. Slag produced can be used for the construction of roads and pavements.

1. Introduction

Global energy requirement has led to massive greenhouse gas emissions [1]. In energy sector there is a need to integrate an efficient technology to produce electricity and control greenhouse gas emissions while using a combustible fuel like coal. Gasification technology is capable of doing efficient work and can mitigate climate change through using fossil fuels more efficiently. In a dry or slurry gasification system, solid coal converts into a gaseous syngas product mainly comprising of carbon monoxide (CO) and hydrogen (H_2), whereas carbon dioxide (CO_2) and low concentrations of methane (CH_4) gases are also produced during the reaction. Coal conversion reaction takes place in the presence of partially available oxidants like oxygen, air or steam. Sulfur present in coal also converts into hydrogen sulfide (H_2S) and carbonyl sulfide (COS) gases. These gases have minor concentrations in syngas [2] and are easily recoverable by known acid gas removal processes [3,4]. Similarly, during gasification nitrogen conversion to nitrogen oxide (NO_X) gases remain limited or negligible because of less oxidizing or reducing nature of gasification process [5]. Instead, nitrogen gets converted into ammonia (NH_3) gas which is easily recoverable and convertible to ammonium fertilizers like ammonium sulfate, ammonium nitrate and urea [6]. Although coal fly ash fines (particulate matter) formed during gasification are recoverable from hot syngas [7], their carbon content depends a lot on the gasification temperature. Temperature is an important parameter for the selection and consideration of capital and operational cost of a gasifier. It highly influences the production of heavy metal components and inorganic materials present in the coal, also known as ash. When this ash is cool down it settle at the bottom of the gasifier and transform into a solid product called the slag [8].

A combined cycle is a set up where clean gas is first burnt in a gas turbine and heat of exhaust gases is then cooled to produce steam that is used in steam turbine of the cycle. This facilitates further addition of valuable commodity electricity to the power house. When natural gas is used in combined cycle, the process is known as natural gas combined cycle (NGCC). However, when clean syngas after particulate removal and desulfurization is used in the combined cycle it gives birth to a technology commonly known as integrated gasification

* Corresponding author. Fax: +82 31 330 7850.
E-mail address: ysyun@iae.re.kr (Y. Yun).

http://dx.doi.org/10.1016/j.joei.2017.05.004
1743-9671/

combined cycle (IGCC). Carbon dioxide removal before use of syngas in the IGCC is known as pre combustion carbon dioxide removal. When a water gas shift (WGS) reactor is present between combined cycle and gasifier, then carbon dioxide can be removed after WGS reaction [9]. During WGS reaction, syngas is reacted with hot steam vapors that give rise to more hydrogen fuel economy and less carbon monoxide content hence left in the syngas [10]. Eq. (1) shows the basic reaction of a water gas shift (WGS) reaction.

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (1)$$

The main concept of IGCC with water gas shift (WGS) reaction is to convert CO of the syngas in to CO_2. With this conversion, maximum possible CO_2 is available in syngas. CO_2 can still be captured and removed before syngas is used in the gas turbine after water gas shift (WGS) reaction. Removal of CO_2 before the combined cycle is an advantage as this minimizes its emission into the atmosphere [11]. This also reduces the size of absorber and stripper unit required after conventional NGCC setup. The CO_2 removal is easy to follow in IGCC systems where it takes place through a physical absorption in a solvent under system pressure. Solvent is later regenerated in a second vessel known as stripper, where pressure is reduced to escape the CO_2 gas from the solvent. Concentrated CO_2 gas is then compressed for storage. When all these steps are performed in a combination then the whole process is called an integrated gasification combined cycle with CO_2 capture, recovery and storage. Effect on gasifier plant efficiency with and without carbon dioxide pre capture in an IGCC entrained bed gasifier is reported earlier [12]. Although removal of CO_2 from an IGCC makes foreign investments more attractive in the country for green power projects [13], CO_2 capture, removal and storage should be considered more than just a policy issue for future sustainability.

When carbon dioxide is captured after combustion from a coal fired power plant or NGCC, it is known as post combustion carbon dioxide removal. For removal of CO_2 like in IGCC here it is also transferred from a mixture of gases into a liquid solvent in the absorber which keeps it captured until desorption process is followed. However in case of post combustion CO_2 removal heat is applied to the stripper to release CO_2 from the chemical solvent (for solvent regeneration). This decreases the thermal efficiency of coal fired power plant and makes it less energy efficient and environment friendly than IGCC systems.

As gasification of carbon bearing materials in slagging gasifier requires high temperature zones inside the gasifier, it increases the structural and operational cost of the gasifier. Gasifying coal at low temperature in a single pass partial slagging gasifier can be cost effective as it is easy to operate at low temperatures but it may impact the operational performance and characteristics of the gasifier products; syngas, fly ash fines and bottom slag. To best of our knowledge and literature search little to no detail work is available highlighting the performance of a partial slagging gasifier. Therefore, main idea of this research work is to study the long-term continuous operational performance of a single pass through partial slagging coal gasifier to note its effect on carbon content in the gasifier fines and slags for their practical implication towards sustainability in the energy sector. Typical full slagging entrained-bed coal gasifier employs an operating temperature of 1400–1600 °C [8].

2. Experimental

2.1. Gasifier operational setup

Gasification tests using pulverized dried Indonesian KPU coal were performed in a two ton per day (TPD) partial slagging entrained bed gasifier at 1100–1300 °C. Oxygen supply to gasifier burners was maintained on the average of 39–42 Nm^3/h. Coal supply to gasifier reaction zone from injection vessel (IV) was stabled around 82.3 kg/h. High purity 99% nitrogen gas at 42–45 Nm^3/h was used as a transportation fluid for coal feeding. Oxygen to coal ratio was set on the average of 0.70. R-type thermocouples were installed to measure temperatures inside the gasifier reaction zone. Differential pressure between the injection vessel and gasifier was kept constant at 1.3 bar for the entire period of gasification operation. Gasifier was operated continuously for seven days. Fly ash fines (particulate matter) produced from coal gasification were captured continuously at cyclone and metal filters while acid gases of COS and H_2S were removed by iron–chelate solution at the desulfurizer. Fig. 1 Illustrates the process schematic diagram of partial slagging coal gasification system used in this work.

2.2. Coal analysis

Subbituminous Indonesian KPU coal with 80–90% passing through mesh size 200 was used for seven days continuous gasification operation. Coal was pulverized and dried simultaneously. Higher heating value (HHV) of coal (kcal/kg) was determined with bomb calorimeter. Analysis data on the dried pulverized coal is given in Table 1.

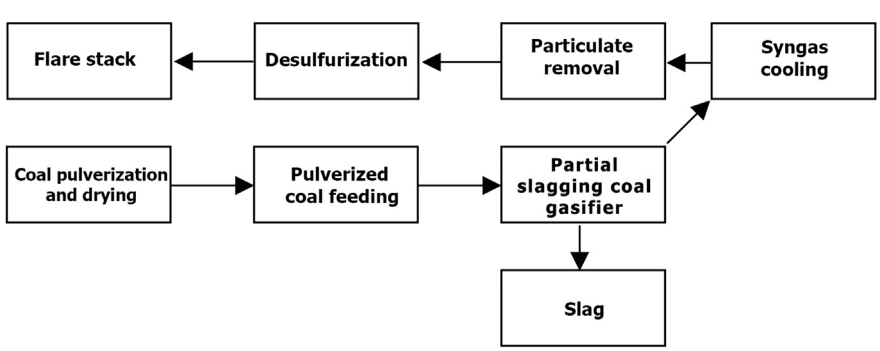

Fig. 1. Process schematic of two ton/day partial slagging coal gasification system.

Please cite this article in press as: J.W. Lee, et al., Partial slagging coal gasifier operational performance and product characteristics for energy sustainability in an integrated gasification combined cycle system, Journal of the Energy Institute (2017), http://dx.doi.org/10.1016/j.joei.2017.05.004