Applied Energy 113 (2014) 318–323

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Development of a novel 2-stage entrained flow coal dry powder gasifier

Shisen Xu [a], Yongqiang Ren [a], Baomin Wang [a], Yue Xu [a], Liang Chen [a], Xiaolong Wang [a], Tiancun Xiao [a,b,*]

[a] China Huaneng Group Clean Energy Technology Research Institute, No. 249, Xiaotangshan Industrial Park, Changping District, Beijing, China
[b] Inorganic Chemistry Laboratory, Oxford University, South Parks Road, Oxford, OX1 3QR, United Kingdom

HIGHLIGHTS

- A 2-stage entrained flow coal dry powder gasifier has been developed and tested in lab, pilot and industrial scale.
- The gasifier can be used to a broad range of coals.
- It has high cold gas efficiency.
- It is stable and has long time, easy to operate.

ARTICLE INFO

Article history:
Received 7 May 2013
Received in revised form 17 July 2013
Accepted 18 July 2013

Keywords:
2-Stage gasifier
Pressure entrained flow
Coal powder

ABSTRACT

Coal-fired gasifiers are the key technology for clean power generation and coal chemical process. This paper presents a 2-stage entrained flow dry powder gasifier in which coal is entrained into the lower chamber burner with oxygen and steam to raise the temperature of the crude gas up to 1700 °C. The lower chamber is linked to the upper gasification chamber through a middle throat, where additional coal and steam is fed to cool down the slag to less than 900 °C for deslagging from the lower chamber bottom.

Various coals have been characterized and gasified with this 2-stage entrained flow dry powder gasifier and comparisons made with single stage gasifiers. The results show that the 2-stage gasifier is suitable for a broad range of coal varieties and gives carbon conversion up to 98.9% with cold syngas efficiency of 83.2% at a pressure of 3.0 MPa, while the oxygen and coal consumption are lower than with the single stage gasifier.

1. Introduction

Coal provides 30.3% of global primary energy needs and generates 42% of the world's electricity (http://www.worldcoal.org/resources/coal-statistics/). In addition, coal is also one of the dominant feedstocks for chemical and fuel production.

Coal gasification offers one of the most versatile and cleanest ways to convert coal into electricity, hydrogen, other valuable energy and chemical products [1–4]. Compared to conventional coal fired power plants, CO_2 capture from coal gasification syngas is far more easily carried out than from the smokestacks of a conventional coal fired plant. The clean syngas can be burned for power generation or can be converted into chemicals or hydrogen through conversion processes [5–9]. Thus coal gasification is the heart of clean coal technology.

There has been extensive research conducted over many years into developing advanced and economical coal gasification technologies [10–19]. Generally coal gasification is carried out in one of three types of reactors based on solid feedstock movement. These three types are fixed bed [20–22], fluidized bed [23–26] and entrained flow bed reactors [17,27–32]. In the entrained flow gasifier, there are two feeding options available, one is slurry feeding and the other is dry feeding, e.g., the so called pneumatic dense flow. The dry feeding system enables higher cold gas efficiencies and carbon conversions. It also permits higher fuel flexibility with the possibility to gasify low rank coals [33–36] with lower emissions. Due to these advantages, more and more attention has been paid to its development.

Commercially used entrained flow dry powder gasifiers mostly adopt a single stage gasification chamber, where the resultant gas contains molten slag [6,14,37,38]. The gas stream is often quenched so that the slag drops to the bottom of the chamber, rather than going with the gasified products. This quench cooling step can prevent the slag from going with the gas products. However, it decreases the cold gas efficiency, and requires installation of a cold gas recycle pump, which leads to higher energy consumption. Also the recycle of the gas increases the gas flow volume, therefore requiring a much larger gas cooler. To prevent the slag and charcoal from going to the syngas stream, 2-stage gasification

* Corresponding author at: China Huaneng Group Clean Energy Technology Research Institute, No. 249, Xiaotangshan Industrial Park, Changping District, Beijing, China. Tel.: +86 15915977798

E-mail address: xiao.tiancun@chem.ox.ac.uk (T. Xiao).

0306-2619/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.apenergy.2013.07.045

technologies have been developed [16], but it used air-blow, and a char recovery pipe is needed to recycle the char into the gasification chamber. On the other hand, the e-Gasifier system adopted 2-stage gasification, but with slurry feeding which has relatively low carbon efficiency.

In terms of efficiency of the current available gasifiers for IGCC application, it has showed that the thermal efficiency, CO_2 emissions and net power output of the slurry feed IGCC is strongly dependent on coal type, and has low performance for low rank coals. On the other hand, the dry feed IGCC is little affected by coal type. The slurry feed IGCC performs closest to the dry feed IGCC when CO_2 is captured and the two highest rank bituminous coals were used [39,40]. This suggests that the coal types have a significant effect on the gasifier performance.

To overcome the above shortcomings in the commercially available gasifiers, we have developed a 2-stage entrained flow dry powder gasifier, which divides the gasifier reactor into two chambers. The super heated crude gas is produced in a lower chamber and is then further reacted with steam and coal from the upper chamber to cool down the slag. This 2-stage dry powder gasifier has been tested in pilot and industrial scales with different types of coal feeds and compared with single stage gasifier performance. Some interesting results have been obtained.

2. Experimental

2.1. Various coal samples as feedstock

The coal samples for this research and development were supplied from Huaneng Coal Ltd. The typical coal samples is crushed, sieved and dried in a mill to a mean particle size of about 120–150 μm, and then transported to an atmospheric hopper by hot nitrogen. The mass of the coal is controlled using a powder mass flow controller of Granucor DK13, DC13 and MT2109 installed on-line in the coal powder conveyance system.

Data for proximate and ultimate analyses of the coals were obtained with a Leco Mac-400 thermogravimetric analyzer and a Perkin–Elmer 2400 II CHN elemental analyzer, respectively.

The ash yield of feed coals was determined by fast ashing method of Chinese Standard GB/T 212-2008 in an electric furnace at 815 °C and sulfur content was determined according to Chinese Standard GB/T214-2007.

The properties and ultimate analysis of the coal samples are shown in Table 1.

2.2. The 2-stage entrained-flow dry powder gasifier

A sketch of the 2-stage entrained flow dry powder gasifier is shown in Fig. 1. The overall gasifier shell is a vertical cylinder, which is divided into two chambers, one lower part, one upper part. The lower chamber is the 1st reaction zone, which is narrow at both ends but wide in the middle. It has 2 or 4 symmetrical spray nozzles attached to the two opposite walls of the lower chamber, which are used for coal powder, steam and oxygen transport. The number of spray nozzles depends on the coal processing capacity. The deslagging outlet is in the high temperature zone of the lower chamber, and liquid deslagging is used. A cooling water jacket on the external surface of the lower chamber is used to recover waste heat.

The upper chamber is longer in length than the lower chamber and provides a second stage reaction zone. Two symmetrical inlets are in the upper gasifier chamber for feeding this second reaction stage with coal powder and steam. As with the lower chamber, a cooling water jacket on the surface of the upper gasifier chamber is used to recover the waste heat.

When in operation, coal powder, oxygen (pure or oxygen-rich) and steam are injected to the lower gasifier chamber, the coal amount to be injected to the lower chamber accounts for 80–85% of the total coal to be gasified. The rest of the dry coal powder is entrained with super heated steam and injected into the upper gasifier chamber. In this configuration of the 2-stage gasifier, the feed to the upper chamber is to quench the raw gasified products from 1400 °C to 900 °C eliminating the need for recycle syngas typically used in single stage gasifiers. The sensible heat from the lower chamber gas is used to pyrolyse the upper-ward fed coal and enables further gasification with steam. The cold gas efficiency and heat effectiveness are thus improved.

The gasified products were analyzed using an on-line GC (HP 5890) equipped with TCD and FID detectors and a packed porous carbon column.

The performance of the gasifier was determined by means of "gasification efficiency" defined as the ratio of the energy content

Table 1
The properties of various coals to be tested for gasification.

Item	Property	Unit	Shenmu	Huating
Moisture	M_t	%	4.9	12.5
Water content in air dried sample	M_{ad}	%	4.86	7.52
Ash content-as received	A_{ar}	%	10.68	17.24
Volatile in dried non-ash sample	V_{daf}	%	36.09	38.10
Fixed carbon	Fc_{daf}	%	63.91	61.90
Basic carbon content	C_{ar}	%	66.71	55.16
H content	H_{ar}	%	4.09	3.57
N content	N_{ar}	%	0.78	0.57
O content	O_{ar}	%	11.97	10.42
Total sulfur	$S_{t,ar}$	%	0.87	0.54
Up-limit heat	$Q_{gr,ar}$	MJ/kg	26.57	21.80
Low limit heat	$Q_{net,ar}$	MJ/kg	25.61	20.78
Temperature of shape change	DT	°C	1150	1300
Softening temperature	ST	°C	1190	1370
Flow temperature	FT	°C	1250	1410

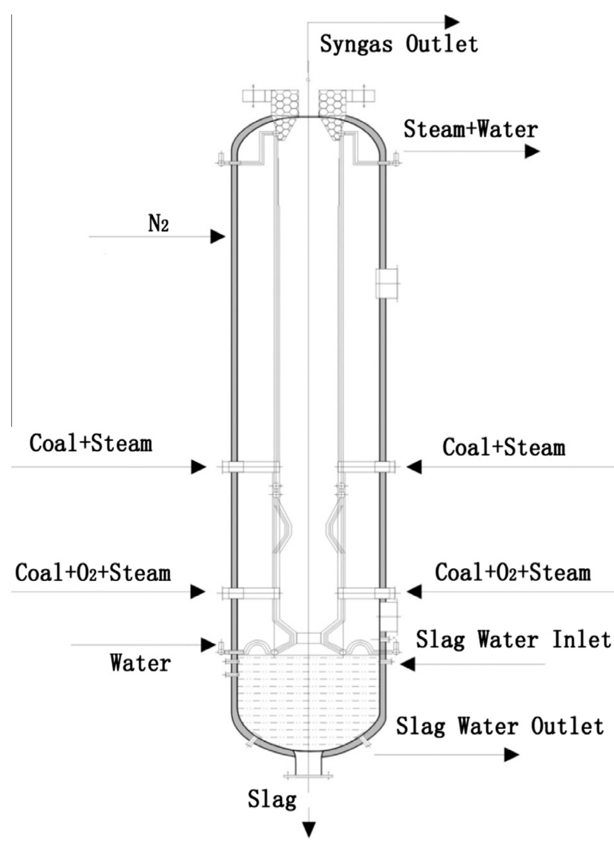

Fig. 1. The schematic cross section of the two-stage entrained flow coal gasifier.