Fuel xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Fuel

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

Partitioning of inorganic elements in pilot-scale and demonstration-scale entrained-flow gasifiers

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HIGHLIGHTS

- Inorganic element concentrations in slag and fly ash from seven gasifiers are given.
- Mass balance closures on low-volatility elements vary from 29% to 625%.
- Elements are classified by enrichment factors.
- Several elements are less volatile in gasification than in combustion.
- Assessments are provided for elements of environmental/technological concern.

ARTICLE INFO

Article history:
Received 29 May 2013
Received in revised form 16 August 2013
Accepted 16 August 2013
Available online xxxx

Keywords:
Entrained-flow gasification
Ash
Slag
Trace elements

ABSTRACT

The integrated gasification combined cycle (IGCC) has been recognized as one of the leading methods of power generation with near zero CO_2 emissions from fossil fuels via carbon capture and storage. A suite of emerging IGCC technologies provide the promise of both high efficiency and reduced capital costs. Many of these operate at elevated temperature and hence a number of inorganic elements (i.e. elements other than C, H, O, N and S) may be present in the syngas at later stages of processing than is typical of conventional processing arrangements. Experimental results are presented for inorganic element distribution in slag and fly ash from seven entrained-flow slagging gasification plants. Data for the Siemens, Louisiana Gasification Technology Inc. (LGTI), Wabash River, ELCOGAS and Shell gasification systems were taken from literature. Data for the CanmetENERGY and Pratt and Whitney Rocketdyne (PWR) systems are presented for the first time. Mass balances and enrichment factors are calculated. All values are available in supplementary data tables. Challenges in data interpretation and general trends are highlighted. Mass balance closures for low volatility elements are within the range of 80–120% for the PWR, LGTI and Shell systems. Closures for the CanmetENERGY, Wabash River and ELCOGAS systems are further from 100%. Accumulation, unaccounted streams, measurement inaccuracy and sampling imperfections can cause poor mass balance closures. Comparison of enrichment factors for slag and fly ash demonstrate that many elements have similar fates in gasification systems as they do in combustion systems, although several elements are less volatile in gasification systems. Partitioning can vary for a given element when comparing different gasification systems and different operating conditions. The assessments of several elements which are of environmental or technological concern are provided as examples.

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1. Introduction

For more than a decade, the integrated gasification combined cycle (IGCC) has been recognized as one of the leading methods of power generation with near zero CO_2 emissions from fossil fuels via carbon capture and storage. A series of studies indicated that it was technically ready for deployment and would increase the cost of electricity in the area of 40% [1,2]. However, as front end engineering design (FEED) studies have been completed, it has become clear that the combination of high capital costs and low net power generation efficiency (~30%) has made the cost of power production via IGCC unattractive [3]. Fortunately, a suite of emerging IGCC technologies provide the promise of both high efficiency (~42% LHV for low rank coal) and reduced capital costs (~4400 $/kW) to provide electricity at a cost on the order of ~$120/MWh with CO_2 emissions in the area of 90 kg CO_2/MWh [3]. The majority of these technologies have not yet been integrated in a power plant, so it is not yet clear how the technologies will interact beyond the major syngas components typically considered in the literature. Many of the emerging technologies operate at elevated temperature and hence a number of volatile and semi-volatile

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0016-2361/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.fuel.2013.08.051

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inorganic elements (i.e. elements other than C, H, O, N and S) may be present in the syngas at later stages of processing than is typical of conventional processing arrangements. More conventional IGCC configurations with CO_2 capture include one or more unit operations with an aqueous or solvent based wash such as full quench, Selexol, Rectisol, amine unit, or desaturator. These units are effective for removal of the portion of inorganic elements that are not captured in the slag or fly ash. Further removal of inorganic elements such as Hg is performed using activated carbon at temperatures near ambient.

In the past, the concern for inorganic element breakthrough has often been ascribed to environmental impact, which of course is important. However, as more advanced technologies are employed, impacts of inorganic elements on reliability, safety and availability become prevalent. An early example of this is the generation of Hg amalgams in the low temperature portion of Rectisol units that necessitate passing the syngas through activated carbon beds before processing by Rectisol [4]. Likewise, HCl has been shown to seriously deteriorate zinc ferrite sorbents for H_2S adsorption [5]. Alkali metals are problematic for gas turbines [6]. As, Cl, P and Sb can degrade the nickel yttria-stabilized zirconia (Ni-YSZ) anodes in solid oxide fuel cells considered for integration with gasification [7,8]. These are just a few examples.

The effects of inorganic elements are not typically well known early in technology development. This is in part due to the lack of published information on the topic of inorganic element partitioning in entrained-flow slagging gasifiers. In this paper, experimental results are presented for inorganic element distribution from seven entrained-flow slagging gasification plants. Mass balances and enrichment factors are calculated. All values are available in supplementary data tables linked to this paper. Challenges in data interpretation and general trends are highlighted. The assessments of several elements which are of environmental or technological concern are provided as examples. It should be noted that this study is not intended to compare the performance of gasification technologies as a wide spectrum of fuels, operating conditions, and sample collecting methods were applied.

2. Materials and methods

2.1. Gasification systems

Several gasification systems are considered in this study. Block flow diagrams for each system are presented in Fig. 1. The diagrams have been simplified by removing streams which do not affect the partitioning of fly ash and slag. The diagrams for some systems are also limited by the information provided in literature. CanmetENERGY operates a 1 tonne/day (1 MW_{th}) gasification facility (Fig. 1a) in Ottawa, Canada for the express purpose of advancing gasification technologies and to provide a better understanding of gasification fundamentals [9]. Pratt and Whitney Rocketdyne (PWR) has been developing advanced compact gasification technology since 2000. From 2004 to 2008, CanmetENERGY was contracted by PWR to perform a series of risk reduction tests to provide information required for the development of a 16 tonne/day gasifier including materials and heat transfer components. From 2007 to 2011, PWR designed, constructed and operated the gasifier (Fig. 1b) at the Gas Technology Institute in Des Plaines, United States [10,11]. Other gasification facilities considered in this study have been thoroughly documented in literature [11,12]. These include the 12 tonne/day (5 MW_{th}) Siemens gasification facility (Fig. 1c) in Freiberg, Germany [13,14], the 2000 tonne/day (160 MW_e) Louisiana Gasification Technology Inc. (LGTI) facility (Fig. 1d) in Plaquemine, United States [15], the 2275 tonne/day (260 MWe) Wabash River facility (Fig. 1d) in Terre Haute, United States [16], the 2400 tonne/day (340 MW_e) ELCOGAS facility (Fig. 1e) in Puertollano, Spain [17], and the 230 tonne/day Shell facility (Fig. 1f) in Houston, United States [18].

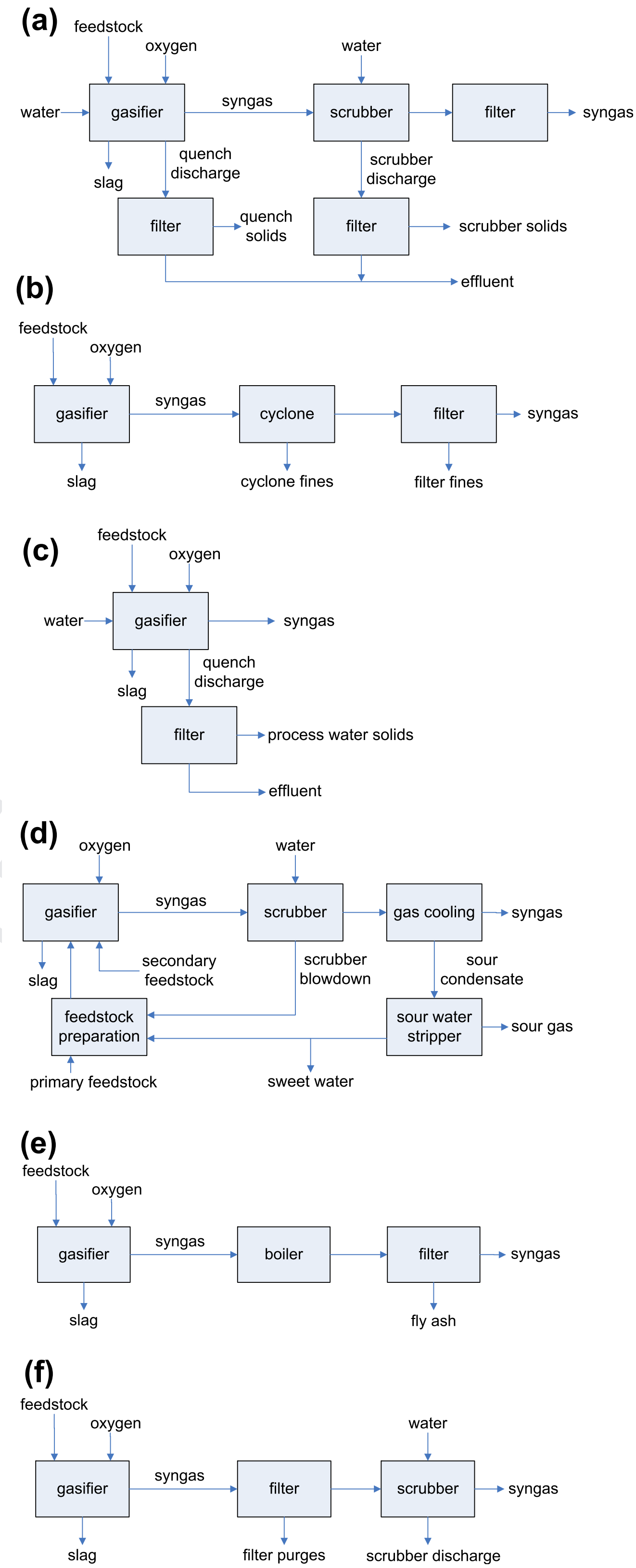

Fig. 1. Block flow diagrams of the CanmetENERGY (a), PWR (b), Siemens (c), LGTI and Wasbash River (d), ELCOGAS (e), and Shell (f) gasification systems. Some streams which are not critical to the mass balances of inorganic elements have been omitted.

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