Fuel 108 (2013) 42–53

Contents lists available at ScienceDirect

Fuel

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

Design and performance evaluation of dry cleaning process for syngas

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ARTICLE INFO

Article history:
Received 12 October 2010
Received in revised form 25 February 2011
Accepted 28 February 2011
Available online 12 March 2011

Keywords:
Hot filtration
Gas cleaning
Pulse-less filtration
Dry scrubbing

ABSTRACT

Coal gasification is one of the most promising options for clean, efficient and continuous power generation, though little progress has been made towards its commercialisation. One of the main hurdles of the commercialisation is reliability of the syngas cleaning process involving separation of critical impurities which can adversely affect the downstream process, and may result in plant shutdown. For example, failure of particulate capturing operation could have instant effect on downstream turbine, catalytic membrane, fuel cell and CO_2 separation, therefore hot filtration is considered as the most critical process step in the gas cleaning process. Failure of sulphur, chlorine, alkali and trace element capture steps may also cause serious damage to the downstream processes but the effect will be noticeable after a relatively longer period of operation. During this period it could be possible to take some corrective actions, either manually or through an automatic control system, to prevent the damage. An automatic control system for particulate system could also be suggested to prevent the damage during filter failure but this would also demand installation of an additional backup filtration unit to continue the operation while failed unit is bypassed for repair. Considering these factors, the reliability of gas cleaning process at reasonable costs appears to be the biggest challenge for the commercialisation of the gasification technologies. A laboratory scale dry gas cleaning unit has been developed and tested at CSIRO to address some of these challenges. This paper illustrates some of the performance results obtained from the tests prior to detailed scale-up studies to be undertaken.

1. Introduction

The commercial success of advanced coal gasification based power generation systems require a reliable and efficient gas cleaning process. While conventional wet gas cleaning is a proven technology with an almost 100% availability factor, it is thermally inefficient, consumes water and produces waste water sludge [1]. Dry hot gas cleaning, on the other hand, has a potential to be very efficient, clean and reliable although the performance of sorbents and particulate filters has yet to be proven at higher temperatures especially above 400 °C [2–5]. Currently a number of demonstration scale syngas cleaning systems are operational [6–9] with an objective to test and improve the performance of various components. Some of these systems are based on semi-wet technology [4,7,8] where at least one stage of water scrubbing is involved in the process. However, outcome of their work [4,7,8] has relevance in both semi-dry and dry gas cleaning process development as the process stages are independent of each other particularly of water scrubbing stages of semi-wet processes. The dry gas cleaning process may have higher concentrations of impurities [1,2,5,6] than what sorbents will be exposed to in water scrubbed syngas [7,8]. Though this warrants a further optimisation of various stages if semi-wet cleaning sorbents and filters have to be adapted for dry gas cleaning process, it is not as big an issue as compared to what would be if these components to be developed from scratch. Considering these facts the common challenges of dry and semi-dry gas cleaning have been identified as frequent degeneration of filter, particularly metal filter [10] and sorbents [11]. The main causes for the degeneration are illustrated elsewhere [11–13].

In the past, performance of a number of filter elements have been carried out for several thousand hours [10] and significant progress has been made to improve the performance of filtration process. Glass ceramic tube filler (CTF) [14] has been developed to minimise the tensile stress on filter during pulse cleaning but design did not progress toward commercialisation as it appears to build stress on filter during filtration. Moving cross-flow granular bed filtration eliminates stress issue on filter element but it offers poorer separation efficiency and not suitable for high pressure applications [15]. Coupled pressure pulse (CPP) is reported to be quite effective in preventing permanent residual pressure build up but more frequent pulsing [4,16,17] increases the possibility of particulate breakthrough. The use of a pipe network and controls for reverse pulsing also appears to be a complex design which

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doi:10.1016/j.fuel.2011.02.041

could be expensive. Attempts have been made to reduce the tensile stress on filter element by optimising the pulse cleaning pressure [18] and reducing the pulse frequency [18,19]. A better cleaned filter allows operation higher face velocities, reduces filter size and costs [18,19]. Strategies and systems have also been developed to minimise corrosion and permanent residual ash deposition of filter elements. The filter surface is protected by protective layers which could either adhere to the surface for example mullite layer on silicon carbide filter (Schumalith series filter) as developed by Pall Corporation or grown on the surface for example aluminium oxide on iron aluminide filters [10]. A similar type of oxide layer is also grown on FeCr alloy filters [10]. A thin layer of protector chemicals or ash particles has also been proposed in a pulse-less filtration system by CSIRO [19] and this approach involves in situ capturing of impurities [16,20] that are responsible for the corrosion of oxide layer of the filter and stickiness of the ash to the oxide layer. This system can also effectively accommodate catalytic conversions processes with the use of catalytic filter elements [21] as there could be no interruption in the reaction due to pulse cleaning. Sulphur is the most abundant impurity in syngas [22] and the halides and alkalis are the most corrosive as well as being responsible for stickiness of the ash [16]. Significant progress in the separation of gaseous impurities by solid sorbents [23–25] has been made, however the issues to be addressed are: (1) poor sorption capacity requiring higher sorbent throughput rates, (2) sorbent degeneration due to attrition and sintering, (3) the complexity of removing trace elements such as mercury, arsenic and selenium above 200 °C [26–31], (4) high costs due to several stages of separation, and (5) higher costs of some of the sorbent preparation and regeneration processes [11,23,32]. In order to address these challenges a dry gas cleaning laboratory scale unit has been developed at tested at CSIRO. This paper illustrates dry gas cleaning process along with the novel concept, design and performance of pulse-less filter. The reliability of filter is crucial to the success of the gas cleaning process therefore performance of the filter simultaneously with the separation of gaseous impurities has been tested in about 200 h of preliminary test runs prior to the detailed test work to be undertaken for the process scale-up. Some results from the preliminary runs are discussed.

2. CSIRO's dry gas cleaning process

The main objective of the process development was to address the issues related to particulate filtration and separation of gaseous impurities in fewer stages (Fig. 1) at highest possible temperature. While these issues addressed, the size and costs reduction were regarded as a necessity to be achieved for successful commercialisation. As shown in Fig. 2, the laboratory system has a syngas recirculation system on the left (skid A) and a gas cleaning system on the right (skid B). Skid B could be separated from skid A and connected to a gasifier to test and verify the performance of various unit operations of the dry gas cleaning process being developed at CSIRO. The compressed syngas is recycled via a Pump P1 (Haskel Model AGD-7, Manufactured by Haskel, Milton Roy). An inline flow meter (GFM2, Bronkhorst model F-113AX-HEE-66-E) is used to measure the volumetric flow. The compressed syngas is then passed through a heat recovery unit (HE2) which recovers heat from the cleaned hot recycled syngas. The preheated syngas is then further heated in an electric heater (HE3, Manufactured by Grimwood, Australia) up to 650–700 °C). The hot gas is then doped with water and water soluble impurities via a Piston–Diaphragm dosing pump (P2, Model KM 281 manufactured by Aldos Pumps). The ash particulates could also be injected into hot syngas via an ash feeder (SF2, manufactured by Metalfab, Inc., USA). Thus a hot simulated syngas could be produced here with some critical impurities which are normally present in the real syngas. The simulated syngas is then passed into the dry hot gas cleaning skid which has a series of sorbent reactors and separators. The impurities of alkali and chlorides are removed in a sorbent reactor R1 (Deaklydechlor reactor) where a sorbent or a mixture of sorbents is injected through a high pressure sorbent feeder (SF1, manufactured by Metalfab Inc. USA). The purpose of the reactor is to provide sufficient residence time to allow effective sorption of gaseous impurities of alkalis and halides onto the sorbent surface. The sorbents and ash from gas are then separated in a cyclone (C1). The sulphur impurities from the syngas are removed by injecting a different sorbent via another sorbent feeder (SF2). The sorbent is then allowed to be mixed and reacted in the sorbent reactor, R2 (Desulphur reactor). The mixture is then passed through a filter (PLF1) to completely remove all the particles. The filter could either be operated in conventional pulsed regime or novel pulse-less regime. The particulate free gas from the filter is then passed through a multi-zoned packed bed of different sorbents to capture trace impurities of S, Se, As, Hg, NH_3, etc. The cleaned hot gas is then recycled after pre-cooling through the heat recovery unit (HE1) and cooling in water cooler (HE2). The temperature and pressure in the various parts of the rig were measured via a number of transducers placed at appropriate positions in the rig. Gas, liquid and solid samples have to be drawn at various points for analysis purposes. A control system and data logger (Field Point System Model cFP-AO-200, manufactured by National Instruments Inc., USA) has been used to control the temperature, pressure and flow of the gas. In the filter testing experiments, both the feeders SF1, and SF3 were used for injecting ash particles into humidified nitrogen gas which was recirculated through the unit.

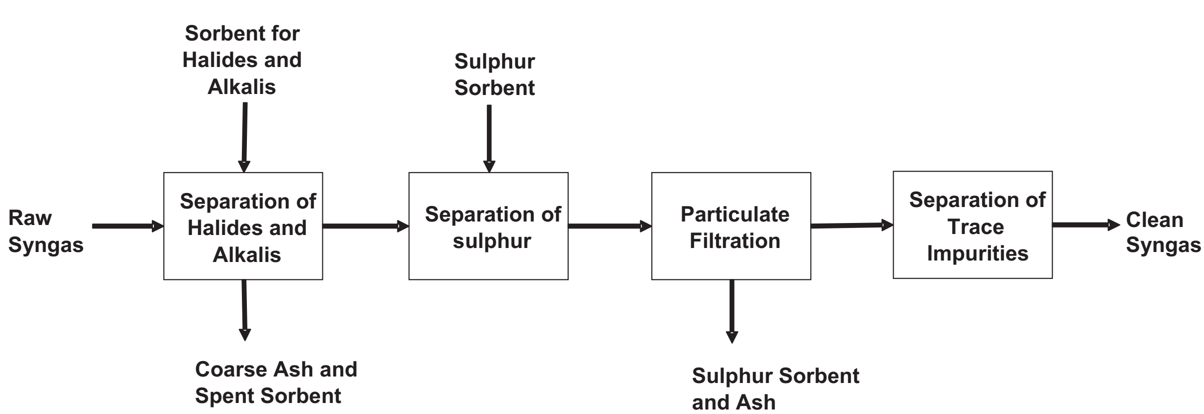

Fig. 1. Block diagram of dry gas cleaning process.