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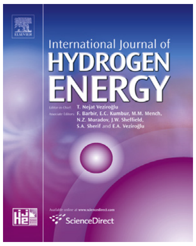

Pressure swing adsorption for coproduction of power and ultrapure H_2 in an IGCC plant with CO_2 capture

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ABSTRACT

The coproduction of power and ultrapure H_2 within an Integrated Gasification Combined Cycle (IGCC) plant implementing CO_2 capture offers advantages in terms of flexible operation while retaining good efficiency. The common design includes an absorption unit for removing CO_2 from a high pressure syngas followed by a Pressure Swing Adsorption (PSA) unit for purifying a part of the resulting H_2-rich gas stream. A drawback of this design consists in the necessity for compression of the PSA tail gas in order to recover the energy available in the residual H_2 content. This paper presents two novel configurations for power and H_2 coproduction with CO_2 capture, entirely based on PSA technology. The first relies on two PSA trains in series (*Two-train PSA*), while the other is able to carry out CO_2 separation and H_2 purification within a single PSA train (*One-train PSA*). The two systems were defined and simulated through a composite model of the whole plant. The process simulation results showed that both the configurations proposed are able to shift between the two energy products without compromising the performance of the plant. The load of the plant could be decreased by increasing the ultrapure H_2 throughput, while maintaining a constant feed of coal to the gasifier. The *Two-train PSA* configuration achieved higher performance in terms of energy efficiency and H_2 purity. The *One-train PSA* configuration returned slightly lower but still good performance, while its design includes a single separation stage instead of two. Additionally, both configurations enable the avoidance of PSA tail gas compression giving an advantage against the absorption-based design. A comparative analysis with results taken from the literature seems to confirm this assertion.

Introduction

Two fundamental characteristics for thermal power plants in the near future are the capability of capturing CO_2 in the most efficient way and the possibility to be operated in a flexible manner. For what concerns the CO_2 emissions, the latest IPCC report clearly pointed out that a strong and immediate commitment is needed if we want to limit the potentially devastating effects of global warming [1]. The energy sector is responsible for a large fraction of anthropogenic greenhouse gas emissions [2]. An intervention in this sector has to be

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undertaken and cannot disregard Carbon Capture and Storage (CCS) [3]. The deployment of other low-carbon energy technologies is also critical, a portfolio of renewable energy sources in the first instance. However, the utilization of fossil fuels is predicted to keep on covering a large share of the power generation in the next decades. CCS allows the exploitation of fossil fuels, while reducing their carbon footprint. Thereby, CCS is an indispensable technology in a reasonable roadmap towards a carbon constrained world, allowing a smooth transition to a long-term scenario dominated by renewable energies. In this context, the concept of flexible operability becomes of primary importance. With the progressive penetration of renewable energy sources into the energy sector, continuous base load operation mode of fossil fuel power plants will become more and more unlikely [4,5]. The intermittent nature of some renewable energy sources (e.g. solar and wind) will deeply modify the energy market and, accordingly, the capacity of efficient operation at part-load will become essential for thermal power plants.

Integrated Gasification Combined Cycle (IGCC) seems to be attractive for capturing CO_2 [6]. The high pressure at which the CO_2 separation can be carried out helps limiting the energy penalty. On the other hand, an IGCC plant is not generally suitable for part-load operation. Operating at reduced loads introduces challenges due to the inertia of the process units (mainly air separation unit and gasifier) and to the elevated auxiliary power demand. One way to deal with that could be the coproduction of hydrogen besides power [5,7]. With the term flexibility in this paper we mean the ability of the plant to shift between two different energy products (i.e. electricity and H_2), resulting from the conversion of a constant coal input, while retaining acceptable efficiency. An IGCC plant which has a variable power-to-hydrogen output may be able, to some extent, to follow the fluctuations in power demand. During low power demand periods, the hydrogen production can be increased to the detriment of the power output. This allows the gasifier and other processing units retaining a working mode close to the design point. The produced ultrapure H_2 can be stored or exported outside the plant. Hydrogen, with certain specifications, is a valuable product for the chemical sector and, possibly, for the transport sector. In this sense, a hydrogen market is predicted to emerge [7,8].

The common IGCC configuration for hydrogen and power coproduction with CO_2 capture found in the literature consists of: coal gasification, low temperature gas clean-up, sour water-gas shift process, CO_2 removal through an absorption process (normally based on a physical solvent, e.g. Selexol), purification (H_2 purity > 99.9%) of a H_2-rich gas fraction via PSA while the remaining part is fed to a gas turbine. The tail gas from the PSA is compressed and added to the fuel gas stream, given its residual H_2 content. Fig. 1 gives a simplified representation of such system. The fraction of the H_2-rich gas stream depends on the established power-to-hydrogen ratio. The performance attainable by the outlined basic configuration, relying on commercially ready technology, has been extensively analyzed in the literature [9–12], also from an economic point of view [8]. Other studies investigated the potential advantages of employing advanced technologies [13,14] and the possibility of differentiating the fuel mixture to be gasified [13–16]. All the mentioned studies rely on PSA technology for the production of ultrapure H_2. Several PSA designs have been proposed in this sense [17–21]. The main objective of an effective PSA design is to maximize the H_2 recovery, while meeting the required purity specifications. A large amount of PSA tail gas would otherwise need to be compressed in order to be fed to the gas turbine and not to waste its energy content. This fuel compression is a complex and energy intensive process. The research for high H_2 recovery has led to increasing complexity of the PSA arrangement. Luberti et al. [22] showed the tradeoff between H_2 recovery and system complexity (productivity accordingly). The aim of the current paper is to address the issue in a different way, which allows for the avoidance of tail gas compression. The idea is to utilize PSA both for the CO_2 separation and for the ultrapure H_2 production. The adoption of the same technology discloses integration opportunities, possibly leading to an efficiency improvement. PSA may be a feasible option for CO_2 capture in coal-fired power plants [23], although absorption seems to generally offer higher overall performance [24]. PSA has also been assessed in a warm gas cleanup arrangement [25] and in sorption enhanced processes [26,27]. The relative outputs were promising but those PSA systems require tailor-made adsorbent materials and composite processes, whereas this work aims to evaluate common technologies. Provided that, the investigation of possible configurations of PSA-based IGCC plants implementing CO_2 capture while coproducing power and hydrogen is a relatively unexplored topic. A demonstration project at the Valero

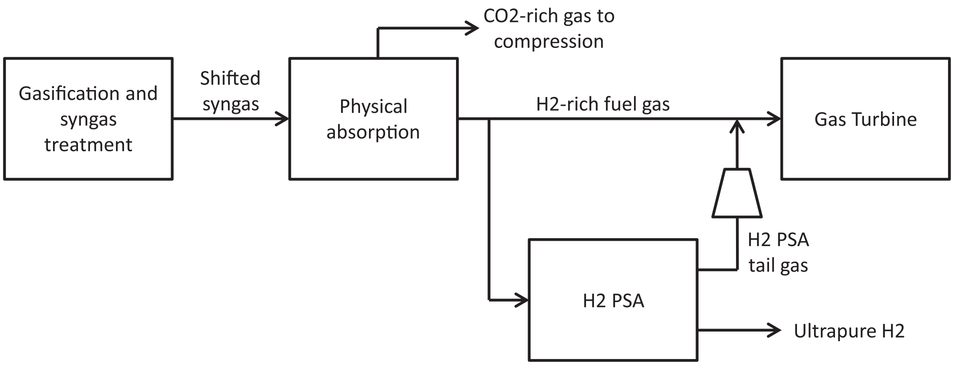

Fig. 1 – Block flow diagram of an IGCC plant with CO_2 separation by absorption and coproduction of H_2 by PSA.