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Process Simulation of CO_2 Chemical Absorption Based on Self-Heat Recuperation Technology for Pre-Combustion Process

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The pre-combustion capture is widely applied in hydrogen production which consists of gasification/reform process with H_2/CO_2 separation process, and the H_2/CO_2 separation process is applied to integrated coal gasification combined cycle power plant (IGCC). IGCC can achieve higher power generation efficiency than conventional power plant. However, CO_2 capture process reduces this efficiency. This is because CO_2 separation from gas mixtures requires huge amount of energy. In this study, we analyzed the pre-combustion process combined CO_2 separation process based on self-heat recuperation technology (SHR). The electric generation efficiency can be improved by SHR compared with conventional IGCC.

1. Introduction

Nowadays, the effects of global warming are becoming more obvious due to increased energy consumption in over the world. Thus, there has been a great discussion about the mitigated global warming. Anthropogenic emissions of greenhouse gases (GHGs) are factor in a causation of global warming. One of the anthropogenic emissions is carbon dioxide (CO2). CO_2 results from the combustion of fossil fuels. Coal has been performed important role as the primary energy source since industrial era in the fifteenth century. Coal could be supplied as a stable energy in the fossil-fuels, because the reserves-to-production ratio (P/R) is longer than others. Total recoverable reserves of coal around the world and current reserves-to-production ratio are estimated at 909 billion tons and 129 years, respectively (U.S.IEA website, 2010). The term is longer than other fossil fuels. However, global demand of coal has expanded more and more.
To use the coal effectively, many researchers have paid more attention about IGCC (Madzivhandila et al. 2009).
IGCC has achieved fuel efficiency rate to 43.5 percent (LHV) (Decamps et al. 2007). IGCC consists of gasification/reform process and power generation process. Recently, IGCC is integrated also H_2 and CO_2 separation processes to reduce CO_2 emission. However, the fuel efficiency rate is approximately reduced 10% by counting H_2/CO_2 separation processes (Decamps et al. 2007, Davison et al. 2007, Riemer et al. 1995).

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Recently, an innovative exergy recuperation technology has been developed for industrial processes: gasification process based on exergy recuperative gasification (Tsutsumi, 2006), heating and cooling thermal process based on self-heat recuperation (Kansha et al. 2009), distillation process based on self-heat recuperation (Kansha et al. 2010(a), 2010(b)). For example, the modularity based on self-heat recuperation for the distillation process was found to reduce the required energy more than 75% in comparison with conventional distillation processes (Kansha et al. 2010(b)). By using the self-heat recuperation technology, the energy requirement of thermal process was drastically reduced (1/3-1/22). Recently, Matsuda et al. (2010) reported that the hydro-desulfurization process with self-heat recuperation technology can reduce the energy input and the exergy input to 46% and 20%.

In this paper, we applied the exergy recuperation technology to CO_2 chemical absorption process for the pre-combustion CO_2 capture. The process modularity of CO_2 gas chemical absorption and stripping processes based on exergy recuperation technology can achieve a considerable reduction in energy consumption. The process simulation of exergy recuperative CO_2 gas separation in pre-combustion capture was conducted by using a process simulator PRO/II (Invensys plc.) to calculate the energy input in comparison with the conventional CO_2 gas separation process based on exergy recuperation.

2. Description of the IGCC with pre-combustion CO2 separation

Figure 1 shows the conventional IGCC with pre-combustion CO_2 separation. Coal is gasified using the air or O_2 rich gas. The O_2 rich gas is produced from cryogenic air separation process (ASU).

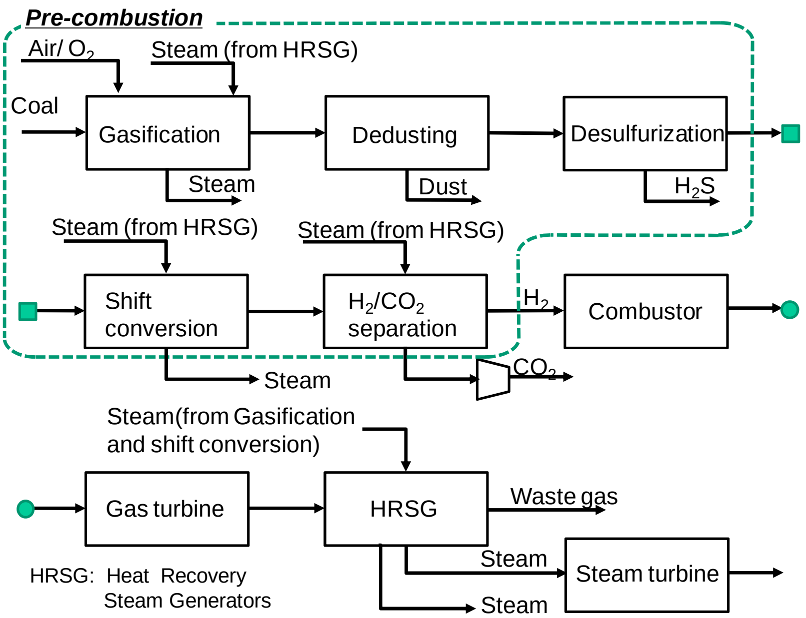

Figure 1: IGCC plant with pre-combustion CO_2 separation

After the gasification process, the gas is fed into dedusting and desulfurization processes, and the dedusted and desulfurized gas is fed into the shift conversion process. In the shift conversion process, steam is used from the gas turbine to produce synthesis gas (H_2/CO_2) by shift reaction. CO shift method has two ways, sweet shift and sour shift. In this paper, we chose a sweet shift.

The CO_2 gas is separated from synthesis gas in the H_2/CO_2 separation process. The H_2/CO_2 separation process is applied chemical absorption (ex. MDEA) or physical absorption process (ex. Selexol). In this paper, we chose a chemical absorption process. The separated CO_2 gas is fed into the compressor to carry CO_2 gas from the ground into sequestration site. The purified H_2 gas is fed into the combustor. In the combustor, electricity is generated and the steam is produced by the HRSG.

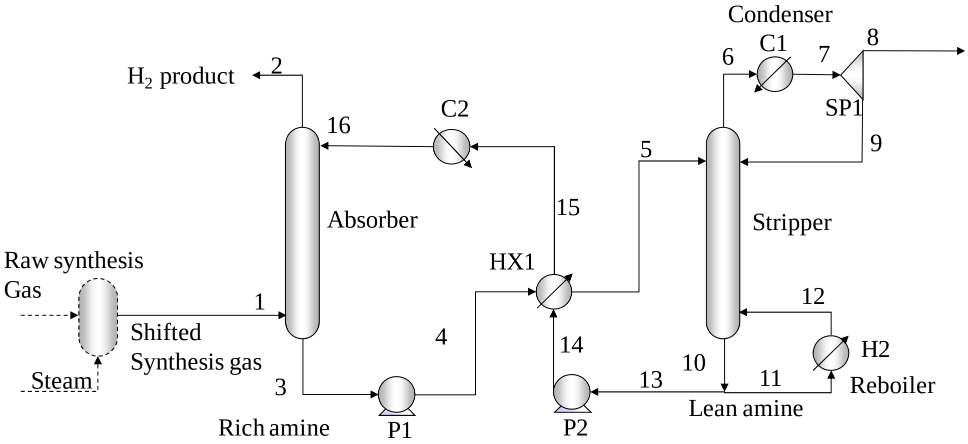

Figure 2: MEA absorption process (The conventional process)

Gasification, dedusting, desulfurization, shift conversion and H_2/CO_2 separation processes are included in pre-combustion process. Especially, the H_2/CO_2 separation process is needed a huge amount of energy to regenerate a CO_2 solvent, leading to that the fuel efficiency rate of IGCC has been dropped from 43.5% to 34.6% (Decamps et al. 2007).

Thus, we proposed a H_2/CO_2 separation process based on self-heat recuperation to reduce the energy consumption in the pre-combustion process.

3. Design of self-heat recuperative module

CO_2 separation process using chemical adsorption method based on self-heat recuperation has been proposed. The proposed process is designed by the following important steps; pairs of feed and effluent streams are selected to recover the heat. To recover the heat among selected pairs, the self-heat recuperation technology is adopted.

In the self-heat recuperation technology, the stream condition is changed by means of the compression of the process stream and the stream can provide self heat to stream of the pair in the heat exchanges, leading to that the self heat of the process stream is recirculated based on exergy recuperation to reduce the process energy consumption. Following series of steps, self-heat recuperative module is constructed.

4. Simulation

Process simulation with PRO/II (Invensys plc.) was conducted to calculate the process energy consumption of absorption process. We used a standard amine package model of PRO/II (Invensys plc.) in the software for this simulation. In thermodynamics data, liquid enthalpy is caluculated by adding a correction for a heat of reaction. The liquid enthalphy and liquide phase density is calculated by ideal method. Vapor phase enthalpy, entropy and density are calculated by Soave-Redlich-Known Modified (SRKM). We assumed that the degree of CO_2 removal is 60-90%.

5. Results & Discussion

The conceptual design of exergy recuperative CO_2 gas separation process is illustrated in Figure 3.

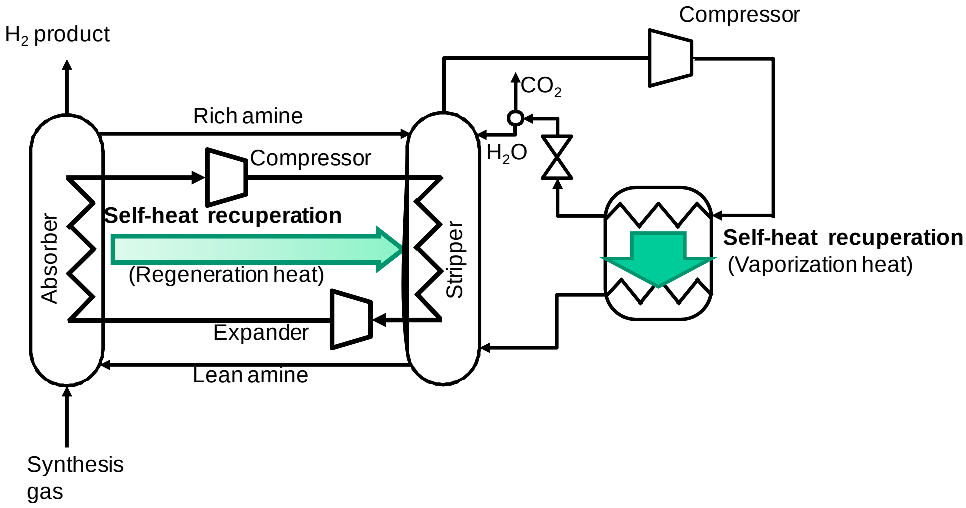

Figure 3: Conceptual design of exergy recuperative CO_2 gas separation process

In the stripper, heat of steam condensation and the cooling heat are recuperated by compression work based on self-heat recuperation technology. The mixture of CO_2 and steam discharged from the top of stripper is compressed adiabatically by a compressor to recuperate the heat of steam condensation as the vaporization heat with self-heat exchanger, reducing the energy consumption for stripping. Furthermore, the heat of exothermic absorption reaction generated in the absorber at low temperature is transformed and reused for reaction heat for solvent regeneration at high temperature by using a Reaction Heat Transformer (RHT) with closed-cycle compression system.

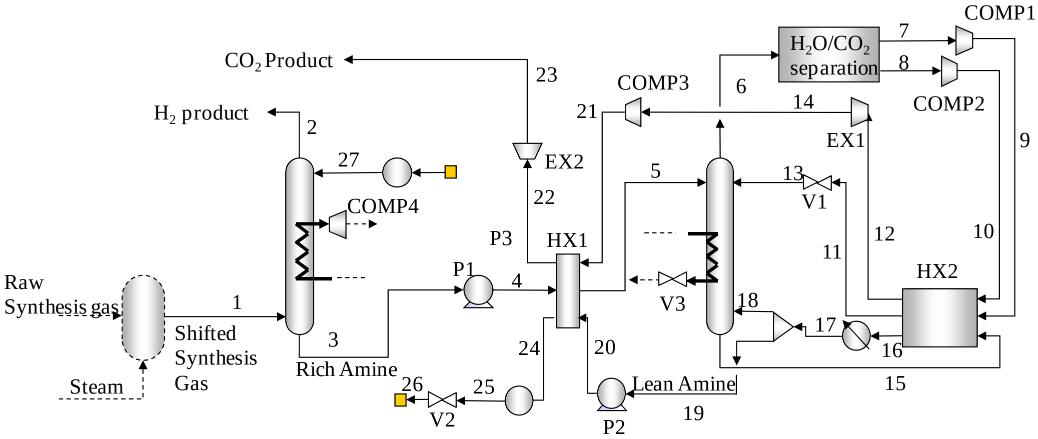

Figure 4: Absorption process based on self-heat requperation thchnology

The proposed process based on exergy recuperative CO_2 gas separation process is illustrated in Figure 4. The energy consumption of the proposed process based on exergy recuperative technology can be decreased huge amount of energy compared with conventional process.

6. Conclusion

In this paper, we proposed a chemical absorption method based on self-heat recuperation technology to reduce amount of energy consumption for pre-combustion and we evaluated the amount of energy consumption of the process as compared with the conventional gas separation process for CO_2 by using a commercial process simulator. The energy consumption of the proposed process based on exergy recuperative technology can be decreased huge amount of energy compared with conventional process.

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