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ScienceDirect

Energy Procedia 86 (2016) 272 – 281

Energy Procedia

The 8th Trondheim Conference on CO_2 Capture, Transport and Storage

Thermodynamic Assessment of Cooled and Chilled Ammonia-Based CO_2 Capture in Air-Blown IGCC Plants

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Abstract

The energy impact of different post-combustion CO_2 capture plants integrated in an advanced air-blown IGCC is simulated in this paper. Ammonia scrubbing is considered as the CO_2 capture technology and chilled and cooled modes are investigated with reference to operation temperatures at the absorber equal to 7°C and 20°C respectively. Ammonia slip is controlled by means of an absorption-desorption cycle just before a final acid wash, where use of the H_2S removed from the coal-derived gas at the desulphurization unit of the IGCC is made.

Focusing on three levels of CO_2 capture, from 80% to 90%, it is possible to appreciate that the cooled mode is promising as far as a reduction of the energy cost related to CO_2 capture is concerned. As a matter of fact, the energy saving, possible when adopting an air cooling system instead of a chilling plant, is significant with the specific primary energy consumption for 90% of CO_2 avoided which decreases from 2.79 MJ/kg_{CO2} to 2.54 MJ/kg_{CO2}, when switching from the chilled to the cooled mode, with a difference equal to about 0.7 percentage point in IGCC efficiency.

Peer-review under responsibility of the Programme Chair of the 8th Trondheim Conference on CO_2 Capture, Transport and Storage

Keywords: Air-Blown IGCC; Chilled ammonia; Cooled ammonia; Carbon capture; SPECCA

1. Introduction

The use of coal for power generation assumes an increasing role in the global energy scenario since security of supply and cost effectiveness of fuel and electricity make coal-fired power plants one of the most viable solutions for

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Peer-review under responsibility of the Programme Chair of the 8th Trondheim Conference on CO_2 Capture, Transport and Storage
doi:10.1016/j.egypro.2016.01.028

power generation. However, the use of coal increases emissions of pollutants and of CO_2. In this framework, Carbon Capture and Storage (CCS) technologies, applied to coal combustion and gasification plants, can assume a significant role in controlling global warming emissions.

The performance of coal-fired power generation plants equipped with CCS systems has been thoroughly studied by the authors. In particular, ultra-super-critical pulverized coal combustion [1-4] and integrated gasification combined cycle [5-8] technologies currently represent the most promising solutions for a CO_2-free power generation from coal.

Although pre-combustion CO_2 capture is a more investigated solution for IGCC power plants [7,8], this paper focuses on post-combustion CO_2 capture and considers the option of the Chilled Ammonia Process (CAP) proposed by Alstom [9], which seems to be a feasible and mature technology in the short term, along with the flue gas scrubbing with MEA. Nevertheless, the CCS energy cost is not negligible and results in lower power plant performance [10]. The CAP technology is suggested also for CO_2 capture in iron and steel industry [11] and applied with membranes [12].

Here, starting from preliminary investigations [6] focusing on possible reductions of such a cost, a more accurate analysis of a CO_2 capture process based on (i) a chilled and on (ii) a cooled aqueous ammonia scrubbing is presented and discussed. In particular, an air-blown IGCC is considered, based on its higher energy conversion efficiency [13]. A proper integration of the IGCC and the CO_2 capture process, with reference to the possibility of using the H_2S removed from the coal-derived gas at the desulphurization unit of the IGCC in the CO_2 capture plant, allows for a better control of the ammonia slip.

Nomenclature and acronyms

AGR	Acid gas removal	LHV	Lower heating value
CAP	Chilled ammonia process	LP, IP, HP	Low, intermediate, high pressure
CCS	Carbon capture and storage	LT, HT	Low, high temperature
CT	Combustion turbine	MEA	Monoethanolamine
ER	CO_2 emission rate (kg_{CO2}/kWh)	SPECCA	Specific primary energy consumption for CO_2 avoided
HR	Heat rate (kJ/MWh)		
HRSG	Heat recovery steam generator	TIT	Turbine inlet temperature
IGCC	Integrated gasification combined cycle	η	Efficiency

2. CO_2–NH_3–H_2O system for CO_2 capture by ammonia scrubbing

Understanding the phase behaviour and the thermodynamics of the CO_2-NH_3-H_2O system is important for engineers and researchers interested in post-combustion ammonia-based CO_2 capture. Such a ternary system forms an electrolyte solution, whose thermodynamic properties must be studied with an appropriate model. In particular, the Extended UNIQUAC thermodynamic model for gas solubility in salt solutions, developed by Thomsen and Rasmussen [14], has been used in this paper. An exhaustive validation of the thermodynamic model was preliminarily carried out and the model results compared with experimental data available in literature. Some representative trends about this validation are reported in [15].

Focusing on the chilled ammonia process, a slurry consisting of a liquid in equilibrium with solid ammonium bicarbonate (NH_4HCO_3) is produced in an absorber. The slurry releases CO_2 at a relatively high pressure, when heated in a desorber, therefore the liquid is cooled and delivered to the absorber for a new cycle. Besides, the CAP layout is equipped with a water wash at the top of both the absorber and the regenerator, because of ammonia slip (NH_3 volatility results in NH_3 vaporization to the flue gas [16]), which is more significant for higher CO_2 absorption temperature. The issue of the NH_3 escape can be solved with other options, as shown in [17] and proven in [18, 19].

In the following, an interesting solution to control ammonia slip is suggested, as an integration of the CCS plant with the desulphurization unit of the IGCC.