Energy 74 (2014) 248–253

Contents lists available at ScienceDirect

Energy

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

Process integration of solar thermal energy with natural gas combined cycle carbon capture

Tristan Lambert [a, b], Andrew Hoadley [a, b, *], Barry Hooper [a]

[a] Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), Melbourne, Australia
[b] Monash University, Clayton, Melbourne, Australia

ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form
3 June 2014
Accepted 4 June 2014
Available online 3 July 2014

Keywords:
Absorption
ALSTOM GT26
Potassium carbonate
Solar tower

ABSTRACT

This project investigates the energy cost of CO_2 capture for NGCC (natural gas combined cycle) power plants and studies the effect of solar thermal energy on the energy penalty for such a system.

The gas turbine used in this study is the ALSTOM GT26. Alongside the standard case, other cases include an EGR (exhaust gas recirculation) and a pre-combustion case that utilises EGR with the capture taking place after the compression stage of the gas turbine. The solar thermal technology used in these simulations is a solar tower system capable of reaching 1000 °C. The integration of the solar energy is used to provide heat to the first of the two combustion chambers in the gas turbine. Cases are optimized for 75% capture.

For a NGCC it was found that using EGR decreased the specific energy penalty as well as capture energy penalty. The pre-combustion case showed a reduction in the energy penalty over the standard and EGR cases but at a reduced capture rate. The addition of solar thermal shows a reduction in the total energy penalty. This is due to a reduction in the total CO_2 produced in the system, hence a reduction in the total CO_2 captured.

1. Introduction

Natural gas power stations are being considered due to their low CO_2 emission intensity. In order to achieve the Australian 2050 targeted emission reductions [1], natural gas systems would also require CO_2 capture systems. Natural gas systems with carbon capture suffer from some notable problems. Low partial pressures of CO_2 in the flue gas leads to low capture driving forces (~4 mol% CO_2 for NGCC (natural gas combined cycle) compared to 10–13 mol% for coal fired power stations [2]). Another potential problem exists with the use of amine solvents which degrade in the presence of oxygen [3]. To counter-act this degradation an inorganic solvent (rate promoted 30%wt potassium carbonate [4]) is used in this study. Carbon capture also reduces the total power output from the power station because of the energy required for regeneration of the solvent.

Parameterised models of capture from NGCC, coal and biomass have been developed [5] to compare the carbon capture from gas, coal and biomass which showed increasing specific energy requirements with decreasing CO_2 flue gas concentration. Mathematical models of NGCC post combustion capture with a MEA (mono ethanolamine) solvent have been developed [6] to determine the optimum conditions for capture. Process simulation modelling has been used to investigate the potential for EGR (exhaust gas recirculation) [7–9] which showed a reduction in the cost of capture with the use of EGR. Multi-objective optimisation with ASPEN Plus® simulation has been used to investigate the effects of capture rate on the power plant performance [4,10].

STE (solar thermal energy) also has the potential to provide power with low emission intensity. Central receiver solar towers have been reported to achieve temperatures of close to 1000 °C in gas turbine systems [11]. Central receiver solar towers use a two-axis mirror array to track sunlight and focus light to a single focal point to maximise the solar radiation intensity [12,13]. This paper aims to integrate the carbon capture and renewable solar to the reduce carbon capture energy penalty.

STE has been investigated for its potential in hybrid power stations with natural gas power stations without capture. In work by Kane et al. [14], parabolic solar troughs have been used to add energy to the HRSG (heat recovery steam generator) along with the flue gas from the gas turbine. The SOLGATE project [15] uses a solar preheat before the combustion chamber into the turbine. Different solar assisted power systems have been discussed [16] with respect to reducing net emission and hybrid operation. Exergy analysis has

---

[*] Corresponding author. Cooperative Centre for Greenhouse Gases (CO2CRC), Melbourne, Australia.

E-mail addresses: tristan.lambert@monash.edu (T. Lambert), andrew.hoadley@monash.edu (A. Hoadley), bhooper@co2crc.edu.au (B. Hooper).

http://dx.doi.org/10.1016/j.energy.2014.06.038

been used to determine the performance of a solar assisted gasification plant [17].

In order to determine the effect of carbon capture on the system, the following performance parameters are defined:

- the energy penalty $\Delta E = \dfrac{P_{\mathrm{w/o\ cap}} - P_{\mathrm{w\ cap}}}{P_{\mathrm{w/o\ cap}}}$, (1)
- the specific energy penalty $\mathrm{SEP} = \dfrac{P_{\mathrm{w/o\ cap}} - P_{\mathrm{w\ cap}}}{\dot{m}_{\mathrm{CO_2}}}$. (2)

The capture rate for all cases is also defined as:

$$\mathrm{CR} = \frac{\dot{m}_{\mathrm{CO_2,gen}} - \dot{m}_{\mathrm{CO_2,em}}}{\dot{m}_{\mathrm{CO_2,gen}}}. \tag{3}$$

This paper presents results for different capture design cases for a NGCC power plant. This paper aims to investigate these cases both with and without solar assistance. The reason for this is to determine the impact of the maximum solar input on the capture process performance, to assess the impact of reduced CO_2 in the flue gas.

2. Methodology

2.1. Case development

The case studies here have been developed to analyse the effect of carbon capture on the NGCC (natural gas combined cycle) power station. The NGCC used for this study is the ALSTOM GT26 combined cycle power plant. One of the features of the ALSTOM GT26 turbine is the dual combustion chambers. This gives a potential for solar integration in that solar heating is able to be used in place of the first combustion chamber of the gas chamber. One of the effects of this is a reduced TIT (turbine inlet temperature) for the first turbine from around 1100 °C when running on natural gas to 1000 °C with solar heat instead of combustion chamber 1. As will be shown, this leads to a reduction in the turbine power, however to counter this another hybrid case with solar heating to 900 °C and then using natural gas top up to the 1100 °C is also considered.

Basic flow sheets are shown in Fig. 1. Each case has minimal heat integration with only steam heat from the HRSG being used to regenerate the solvent in the reboiler. The following three plant configurations were used in this study.

2.1.1. NGCC

The first case is a standard NGCC set up with post combustion capture. The flue gas from the gas turbine is sent to the HRSG to generate steam for the steam turbines. The flue gas is then cooled before being sent to the absorption column. The CO_2 absorbed is released and the solvent is regenerated in the stripper. Stripper reboiler energy is provided by low pressure steam from the steam cycle.

2.1.2. NGCC with exhaust gas recirculation

The second case is an EGR (exhaust gas recirculation) in order to increase the partial pressure of CO_2 in the flue gas. The recycled exhaust gas is recirculated around and cooled for the gas turbine. The EGR is limited by the excess oxygen required for the combustion in the gas turbine. The recirculation rate (ratio of recirculated gas:exhaust gas) for the standard NGCC is 1:1 while for the solar case with a lower fuel rate is 3:1.

2.1.3. NGCC pre-combustion

The final case also tries to increase the partial pressure of the CO_2 in the stream sent to capture. In order to achieve this, capture was performed at high pressure. To achieve high pressure capture, the gases (fresh air + EGR) from the gas turbine compressor are sent to the capture plant prior to being sent to the combustion chamber. After the compression stage the gas is sent through a heat exchanger which conserves the heat from compression for the turbine. The heat is recovered into the returning gas stream from the absorber.

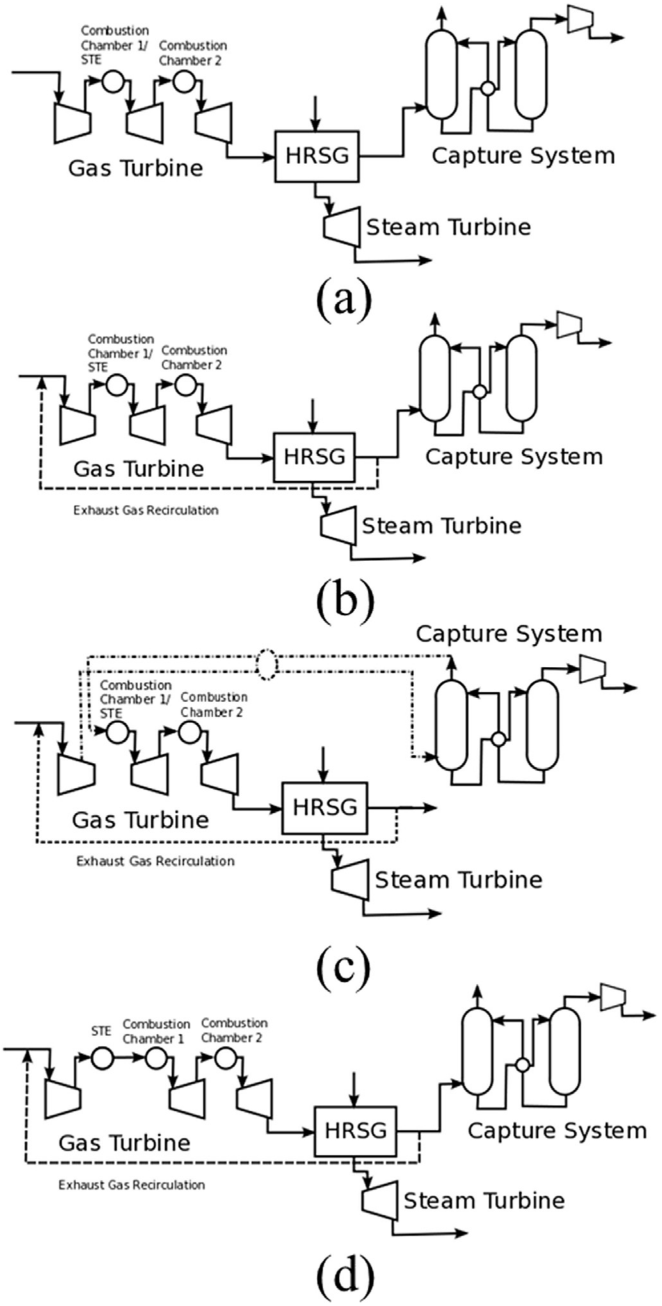

Fig. 1. Basic PFDs for the cases studied: (a) is the standard post combustion capture, (b) is the EGR case, (c) is the pre-combustion, high pressure capture case and (d) is the solar with NG top up in the first stage.

2.2. Simulation

The NGCC and capture plants were simulated using ASPEN Plus$^{®}$ (version 7.3) simulation software. The details of the simulated gas turbine are shown in Table 1. The gas turbine is modelled using