Available online at www.sciencedirect.com

ScienceDirect

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

Economic implications of pre- and post-combustion calcium looping configurations applied to gasification power plants

*Calin-Cristian Cormos**

Babes – Bolyai University, Faculty of Chemistry and Chemical Engineering, 11 Arany Janos Street, RO-400028 Cluj-Napoca, Romania

ARTICLE INFO

Article history:
Received 28 March 2014
Received in revised form
1 May 2014
Accepted 6 May 2014
Available online 2 June 2014

Keywords:
Gasification
Carbon capture and storage (CCS)
Calcium looping
Economic evaluations

ABSTRACT

Gasification is a promising conversion technology to deliver high energy efficiency simultaneously with low energy and cost penalties for carbon capture. This paper is devoted to in-depth economic evaluations of pre- and post-combustion Calcium Looping (CaL) configurations for Integrated Gasification Combined Cycle (IGCC) power plants. The poly-generation capability, e.g. hydrogen and power co-generation, is also discussed. The post-combustion CaL option is a gasification power plant in which the flue gases from the gas turbine are treated for CO_2 capture in a carbonation–calcination cycle. In pre-combustion CaL option, the Sorbent Enhanced Water Gas Shift (SEWGS) feature is used to produce hydrogen which is used for power generation. As benchmark case, a conventional gasification power plant without carbon capture was considered. Net power output of evaluated cases is in the range of 550–600 MW with more than 95% carbon capture rate. The pre-combustion capture configuration was evaluated also in hydrogen and power co-generation scenario. The evaluations are concentrated for estimation of capital costs, specific investment cost, operational & maintenance (O&M) costs, CO_2 removal and avoidance costs, electricity costs, sensitivity analysis of technical and economic assumptions on key economic indicators etc.

Introduction

The world is facing a continuous increase of energy demand [1], most of this increase being covered by stepping up the fossil fuels usage. For instance, in European Union (EU) the fossil fuels cover more than 50% of power generation capacity, from which about 60% is based on coal [2]. The predictions show that fossil fuels will remain the backbone of power generation sector in the years to come. These imply an increase of greenhouse gas emissions (especially CO_2). Subsequently, more and more attention is devoted to mitigation of the greenhouse effect by reducing the gas emissions which have such effect (e.g. CO_2, CH_4 etc.).

Various methods can be used for reducing CO_2 emissions. For instance, large scale deployment of renewable energy sources (e.g. wind, solar, biomass) is targeted. At EU level, 27% of the energy demand is expected to be covered from

* Tel.: +40 264 593833; fax: +40 264 590818.
E-mail address: cormos@chem.ubbcluj.ro.
http://dx.doi.org/10.1016/j.ijhydene.2014.05.033

renewable energy sources by 2030 [3]. The greenhouse gas emissions are expected to be reduced by at least 40% below the 1990 level for the same time period. Developing and large scale deployment of high energy efficient applications is also an efficient way to reduce greenhouse gas emissions. Within this context, Carbon Capture and Storage (CCS) technologies are of paramount importance for transition to low carbon economy. Development of CCS technologies will make acceptable from CO_2 emission point of view the vast coal reserves available worldwide [4]. Basically, CO_2 capture for power plants or other energy intensive industrial processes (e.g. cement, metallurgy, petro-chemistry etc.) can be done by one of the three ways: (1) post-combustion capture from flue gases resulted from fuel burning; (2) pre-combustion capture in which CO_2 is removed from the syngas generated by fuel partial oxidation (e.g. reforming, gasification); (3) oxy-combustion in which the fuel is burnt using pure oxygen and recycled CO_2 [5].

One of the main drawbacks of post-combustion carbon capture technology based on gas–liquid absorption is the high thermal duty to regenerate the solvent, along with power consumption to compress the captured CO_2 up to 120–150 bar for transport and injection in geological storage. The heat consumption to regenerate alkanolamines is in the range of 3 GJ/t CO_2. This thermal burden of the carbon capture unit implies an energy efficiency drop of the power plant in the range of 10 net electricity percentage points [5–8]. The pre-combustion carbon capture using solvents (either physical or chemical solvents) recovers a bit of this energy penalty taking advantage of significantly higher CO_2 partial pressure. But still the energy penalty for carbon capture is in the range of 8 net electricity percentage points [8].

As innovative carbon capture method, chemical looping is a particular promising option to tackle both increasing overall plant energy efficiency and reducing CO_2 capture energy and cost penalties [9]. From various chemical looping systems, the present work is focused on calcium looping (CaL) which is based on the calcium oxide sorbent capacity in capturing the CO_2 from flue gases and syngas. CaL technology utilizes a dual circulated fluidized bed (DCFB) system in which a cycle of calcium-based sorbent to capture CO_2 as $CaCO_3$ from the flue gas in the carbonation reactor and to regenerate the sorbent (CaO) in the calcination reactor and CO_2 is released in a concentrated form, ready for storage. CaL technology development is now at up to 10 MW scale pilot plants [10,11]. Coal-fired power plants as well as other energy intensive industrial processes (e.g. cement industry) are considered as the main application for CaL process. The chemical reactions of the CaL cycle are the following:

$$CO_2 + CaO \Leftrightarrow CaCO_3 \quad \Delta H = -178\ \text{kJ/mole} \tag{1}$$

$$CaCO_3 \Leftrightarrow CaO + CO_2 \tag{2}$$

Since the calcination reaction (2) is highly endothermic, additional fuel has to be burned in oxy-conditions (oxygen and recycled carbon dioxide) to cover the reaction duty. Both gas streams leaving carbonation and calcination reactors are cooled down to generate steam which is integrated in the steam cycle of the Combined Cycle Gas Turbine (CCGT).

Calcium looping applied to pre-combustion capture configuration implies the reaction between carbon monoxide and steam to give carbon dioxide and hydrogen. Calcium oxide has the role to capture CO_2 by forming calcium carbonate and to displace the reaction equilibrium to the right (towards hydrogen). The global reaction (Sorbent Enhanced Water Gas Shift – SEWGS) is presented below:

$$CO + H_2O + CaO \Leftrightarrow CaCO_3 + H_2 \tag{3}$$

Calcium carbonate is then sent to calcination reactor for decomposition to release the captured CO_2 and regenerate the solvent. Besides capturing the carbon dioxide, reaction (3) is also concentrating the syngas energy in form of hydrogen that can be used for power generation (in a hydrogen-fuelled gas turbine) or purified and used in other applications.

CaL technology has important features which make this method attractive for capturing carbon dioxide from fossil power generation sector (especially coal and lignite) as well as other energy-intensive industrial applications. As shown by this work, which is devoted to detailed economic evaluations of pre- and post-combustion CaL options, as well as the previous work of the author devoted to technical and energy integration aspects of such cycles [12], CaL has the following key advantages: (i) lower energy and cost penalties for carbon capture in comparison to gas–liquid applications; (ii) usage of non-toxic, widespread and inexpensive materials which, after deactivation, can be used in cement industry and (iii) simplified plant designs embedded with high energy conversion features e.g. high temperature heat recovery for increasing the energy efficiency.

The paper assesses the economic aspects of CaL cycles in both pre- and post-combustion configuration for gasification power plants. Various aspects of economic evaluation were covered: estimation of capital costs and specific cost investment, operational and maintenance (O&M) costs, power and hydrogen costs, CO_2 removal and avoidance costs, cumulative cash flow analysis, sensitivity studies to evaluate the influence of operation conditions (e.g. sorbent make-up rate) and economic parameters (e.g. fuel cost, CO_2 storage cost etc.) on electricity cost. In order to boost the overall energy efficiency and to underline the energy vectors poly-generation capability, the hydrogen and power co-generation scenario was also analysed. The evaluated power plant concepts generate 550–600 MW net electricity and a hydrogen output up to 200 MW_{th}. As a benchmark option, a similar (same gasifier) IGCC power plant without carbon capture was used.

Configurations of gasification CaL plants and their technical assessment

Gasification is an old energy conversion technology, the first gasification plants started more than 180 years ago [13]. In the last decades, due to the need to enhance the primary energy supply sources and the environmental protection, the gasification started a new development cycle. The main advantages of gasification in terms of enhancing energy supply sources and environmental protection relies in the possibility to process lower grade fuels (coal, lignite, biomass, solid wastes etc.)