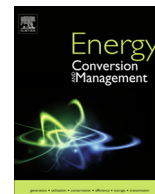




Contents lists available at ScienceDirect

Energy Conversion and Management

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

Carbon capture and utilization for sodium bicarbonate production assisted by solar thermal power

D. Bonaventura^{a,b}, R. Chacartegui^{a,*}, J.M. Valverde^a, J.A. Becerra^a, V. Verda^b

^a University of Seville, Spain

^b Politecnico di Torino, Italy

ARTICLE INFO

Article history:
Available online xxx

Keywords:
CO₂ capture
Coal fired power plant
CCS
CCU
Dry carbonate process
Trona
Sodium bicarbonate

ABSTRACT

In this paper, a novel carbon capture and utilization process is proposed. It is based on using a fraction of the captured carbon dioxide to produce sodium bicarbonate, a widely used product in the chemical and food industries. The process couples the Dry Carbonate process for carbon dioxide capture with sodium bicarbonate production. Raw material is trona or sodium sesquicarbonate dehydrate, which is a relatively abundant mineral composed by approximately 46% sodium carbonate and 35% sodium bicarbonate by weight. In the process, trona is firstly converted into sodium carbonate in a fluidized bed reactor operated at 180–200 °C and 1 bar. Heat required in the fluidized bed reactor for decomposing trona can be supplied by renewable sources such as low/medium temperature solar energy or biomass. A fraction of the sodium carbonate generated is recirculated for carbon dioxide capture by means of the dry carbonate process. The rest is converted to sodium bicarbonate in a carbonating tower through the reaction with carbon dioxide and water. After separation of sodium bicarbonate and other salts from water, the sodium bicarbonate produced is suitable for direct sale. The use of renewable sources for supplying the energy required at the sorbent regenerator and for trona decomposition yields a near-zero carbon dioxide emissions global system. As case of study, carbon dioxide capture coupled to sodium bicarbonate production has been analysed for a 15 MW_{el} coal fired power plant. Heat required in the carbon capture process penalizes the global system efficiency by a 10.2%, which is reduced just to the electricity parasitic consumption for solids transport and carbon dioxide compression (~3%) if renewable energy sources are integrated. From an economic perspective, the penalty in electricity consumption is fully compensated by the new by-product sales. Taking into account the reduction of electricity sales and current prices of trona and sodium bicarbonate a return of investment is obtained in the range between 3 and 8.7 years with an internal rate of return over 12%. These values improve the current forecast of any other carbon capture and storage process up to date, which suggests a high interest of the proposed conceptual integration specially for regions where trona is widely available.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

A complete replacement of fossil fuels by renewable energies is not feasible in the short-term. Thus, fossil fuel power plants should be urgently retrofitted with CO₂ capture and sequestration (CCS) processes as a necessary measure to limit global warming below 2 °C [1]. CCS would allow continuing the use of fossil fuel until a deeper penetration of renewable energy sources into the grid is attained in an orderly fashion. CO₂ capture and utilization (CCU) for commercial purposes would help mitigating capture costs that mainly hinder the commercial deployment of state of the art CO₂ capture technologies. Current anthropogenic CO₂ emissions

(around 35 Gt/y) largely exceed the amount of CO₂ used in chemical processes (~200 Mt/y). However, promoting CO₂ utilization routes for the production of valuable chemicals could be a starting point to promote the deployment of CO₂ capture technologies [2]. According to International Energy Agency (IEA) projections, the CCS share of cumulative emissions reduction to achieve the 2 °C target would require about 3500 large-scale CCS projects in operation by 2050. Only about 15 large-scale CCS commercial projects are in operation to this date of which Boundary Dam in Canada is the only coal fired power plant applying CCS in the power sector. Yet, it is estimated that abandoning CCS in the power sector would increase the investment required over 40% in the 2 °C scenario [3]. Moreover, post-combustion capture technologies have the greatest potential for reduction of CO₂ emissions in the short term because

* Corresponding author.

Nomenclature

Components

CARBONATING TOWER CO₂ capture and NaHCO₃ production reactor
 CARBONATOR CO₂ capture reactor
 COAL FIRED PLANT coal fired plant for electricity production
 COMP1 compressor CO₂ (1–10 bar)
 COMP2 compressor CO₂ (10–25 bar)
 COMP3 compressor CO₂ (25–75 bar)
 COOL CO₂ (20 °C) intercooler
 FLUIDIZED BED fluidized bed reactor
 HEATEX1 H₂O-flue gas heat exchanger
 HEATEXCH NaHCO₃-Na₂CO₃ Heat exchanger
 HEATEXT Trona - Na₂CO₃ heat exchanger
 HEATEXW H₂O - steam + CO₂ heat exchanger
 INTERC1 CO₂ (20 °C) intercooler
 INTERC2 CO₂ (20 °C) intercooler
 INTERC3 CO₂ (20 °C) intercooler
 IP/LP intermediate pressure/low pressure
 PTC parabolic trough collector technology
 REGENERATOR sorbent regenerator
 SEPA1 solid-gas separator
 SEPA2 solid-gas separator

Streams

CARBOUT final product from carbonator
 CO2 CO₂ recovered from the system

CO2 IN CO₂ entering the system
 CO2 TO STORAGE CO₂ to the storage system (20 °C, 75 bar)
 CO2 + STEAM CO₂ and steam (220 °C)
 CO2 + WATER CO₂ and water(95 °C)
 CRUSHED TRONA crushed trona
 FGPLANT flue gas exits the coal fired plant
 FLUE flue gas exits the carbonator
 FLUID OUT chemical products exits the fluidized bed reactor
 HOT STEAM super heated steam (205 °C)
 HOT TRONA hot trona (125 °C) entering the fluidized bed reactor
 MAKE UP sorbent MAKE up
 NA2CO3 COLD (Fig. 5) regenerated Na₂CO₃ (80 °C)
 NA2CO3 COLD (Fig. 6) cooled Na₂CO₃ (40 °C)
 NA2CO3 HOT (Fig. 5) regenerated Na₂CO₃ (200 °C)
 NA2CO3 HOT (Fig. 6) hot Na₂CO₃ (220 °C)
 NA2CO3 IN chemical products entering the NaHCO₃ production reactor
 NAHCO3 NaHCO₃ produced by the system
 NAHCO3 COLD solids exits the carbonator (60 °C)
 NAHCO3 HOT solids entering the regenerator(140 °C)
 WATER IN (Fig. 5) water CO₂ capture reactor
 WATER IN (Fig. 6) cold water (35 °C)
 WATER OUT process water

they can be retrofitted to existing fossil fuel power plants and are also applicable to other industrial processes.

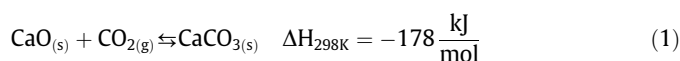
Up to date the only post-combustion capture technology commercially available at the necessarily large-scale of coal fired power plants is based on chemical absorption by amines dissolved in water. In this post-combustion capture system, the exhaust gases stream from the power plant is passed through an absorber column where it comes into contact with the liquid amine flowing downwards, which allows CO₂ to be chemically absorbed by the amine. The CO₂ rich amine solvent is then pumped to a regenerator, where heat is supplied to reverse the chemical reaction and release relatively pure CO₂ for its compression, transport and storage while the CO₂ lean liquid amine is pumped back into the absorber to be reused [4]. Although temperatures for CO₂ desorption are not high (~130 °C) sorbent regeneration in this process requires a relatively high amount of energy to heat the large volume of water where amines are dissolved. Thus, the energy required per ton of CO₂ captured is about 3.3 GJ/ton_{CO2} for an advanced monoethanolamines (MEA) system whereas 3.9 GJ/ton_{CO2} are required for a typical aqueous MEA system [5]. On the other hand, post-combustion capture by MEA suffers from other serious issues related to toxicity, corrosion and degradation [6]. Furthermore, amines have a relatively high cost (>1000 €/ton), which is a major problem taking into account the large scale of commercial CCS applications [7].

Thus, there is a need to develop novel post-combustion capture processes using cheap, widely available and non-toxic materials at reduced cost and energy penalty. In this line, novel amine-based solid sorbents based on direct steam stripping desorption have shown an improved performance [8]. In Ref. [9] an organic solvent was added to a CO₂ rich, aqueous ammonia/CO₂ solution under room temperature and pressure conditions. The sorbent was regenerated by using low-temperature heat, with a reduced thermal energy requirement. In Ref. [10] novel absorbents were studied using both single and mixed amine-based absorbents. Ref.

[11] presents a review about the impact of uncertainty in the sorbent thermo-physical properties on the design and operation of components and processes involved in CO₂ capture.

CO₂ capture processes using dry solid sorbents capable of capturing CO₂ from flue gas streams by physical adsorption show potential advantages compared with conventional CO₂ capture systems using aqueous amine solvents [12]. Thus, a variety of promising adsorbents such as activated carbonaceous materials, microporous/mesoporous silica or zeolites, carbonates, and polymeric resins have been proposed in the recent literature [12]. As a common feature, these solid sorbents require very small amounts of heat for regeneration although their capture capacity is generally low. Ref. [13] proposes the use of power plant's waste heat for CO₂ capture by nanomaterials properly designed to overcome the competitive adsorption of CO₂ and H₂O.

The Calcium-Looping process is a promising 2nd generation post-combustion process validated at the pilot level (1–2 MW_{th}) that uses Calcium Oxide (CaO) derived from cheap (~10 €/ton) and abundant natural limestone to capture CO₂ from flue gas. The process is based on the reversible carbonation/calcination chemical reaction at high temperatures [14]:



Carbonation proceeds at a satisfactory fast rate at temperatures in the range 625–680 °C while the reverse calcination reaction should be carried out at 900–950 °C under high CO₂ partial pressure [14]. The dry sorbent is repeatedly cycled between two reactors. In one reactor (carbonator) carbonation of CaO particles serves to capture CO₂ from the flue gas. The carbonated particles are then circulated into another reactor (calciner) where sorbent regeneration takes place by calcination. To close the cycle, the regenerated CaO particles are returned back into the carbonator, leaving a concentrated stream of CO₂ in the calciner ready for compression, transport and sequestration. However, a main drawback

Download English Version:

<https://daneshyari.com/en/article/5012468>

Download Persian Version:

<https://daneshyari.com/article/5012468>

[Daneshyari.com](https://daneshyari.com)