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Energy recovery opportunities from mineral carbonation process in coal fired power plant

S. Moazzem, M.G. Rasul*, M.M.K. Khan

Central Queensland University, School of Engineering and Built Environment, Rockhampton, Queensland 4702, Australia

HIGHLIGHTS

- ► Mineral carbonation technology is one the carbon capture and storage technologies.
- ► Exothermic heat energy can be recovered from mineral carbonation process.
- ► Mineral carbonation process is energy self-sufficient.
- ► Thermodynamic mass and energy balance model is developed for mineral carbonation.

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ABSTRACT

Various carbon dioxide (CO_2) capture and storage (CCS) technologies are available worldwide to mitigate the effects of global warming. Mineral carbonation technology is one of the types of CCS technology. In this process gaseous CO_2 is converted into geologically stable carbonates. This process has some potential advantages compared to other available CCS technologies which have attracted the attention of researchers for further development of this technology for sequestering CO_2. One of the potential benefits of this technology is its exothermic reaction process. This exothermic heat energy can be recovered and used in other energy consuming components of carbonation plant. Heat energy from the products of the carbonation process can also be captured. This technology has not fully been developed yet, in particular for implementing it into power plants. In this study a thermodynamic mass and energy balance model is developed using Matlab/Simulink software for investigating energy recovery opportunities. Wollastonite mineral is used as feed stocks. The amount of heat energy which can be recovered at different carbonation temperatures is determined and analysed for a case study power plant with capacity of 1400 MW. It is found from this study that the carbonation process in case study power plant is energy self-sufficient, even only by the exothermic heat produced from the reaction and no heat recovery is needed from the products of carbonation process. It is also found that the energy required to supply to the carbonation plant (i.e. to grinder and compressor) decreases with increase in carbonation temperature. The surplus exothermic heat energy and heat energy from carbonated products can be utilized to reduce the fuel energy required for the existing power plant.

1. Introduction

Mitigation of carbon dioxide (CO_2) concentration in the atmosphere to reduce global warming is one of the vital issues for today's world. Presently, a number of technologies are available to reduce CO_2 emissions to the atmosphere from various process industries that is known as carbon capture and storage (CCS) technology or alternatively carbon capture and sequestration technology. Mineral carbonation technology is one of the types of CCS technologies where CO_2 is stored into stable solid products which provide potential advantages over other available CCS technologies. The major advantages of CO_2 sequestration by mineral carbonation are:

Environmental safety: Mineral carbonation produces stable carbonated products/materials through carbonation reaction. This product can be stored at an environmentally suitable location or reused in other industrial processes, such as mine reclamation, construction or land filling [1].

Availability of the raw materials: Raw materials for binding CO_2 in carbonated products exist in vast quantities across the world. In the Australian scenario, carbonation technology is seen to be an attractive option for CO_2 sequestration due to the extensive deposits of minerals in Australia [2,3].

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* Corresponding author. Tel.: +61 7 4930 9676; fax: +61 7 4930 9382.
E-mail address: m.rasul@cqu.edu.au (M.G. Rasul).

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Table 1
Composition of some selected rocks and pure minerals and their potential CO_2 sequestration capacity [8].

Rock mineral	MgO [wt%]	CaO [wt%]	RCO_2 [kg/kg][a]
Serpentinite[b]	~40	~0	~2.3
Serpentinite, $Mg_3Si_2O_5(OH)_4$	48.6		1.9
Dunite[b]	49.5	0.3	1.8
Olivine, Mg_2SiO_4	57.3		1.6
Wollastonite[c]	0.8	43.7	2.9
Wollastonite, $CaSiO_3$		48.3	2.6
Talc[c]	34.7	0.0	2.6
Talc, $Mg_3Si_4O_{10}(OH)_2$	31.9		2.9
Basalt	6.2	9.4	7.1

[a] RCO_2 = mass ratio of rock to CO_2 required for CO_2 sequestration.
[b] Lackner et al. [10].
[c] Wu et al. [11].

Carbonation reaction produces exothermic heat energy. Carbonated products also contain heat energy which is another source of energy recovery [4,5]. The advantages of carbonation technology have attracted the attention of researchers in this field for further development of mineral carbonation technology as a viable option of CCS [5].

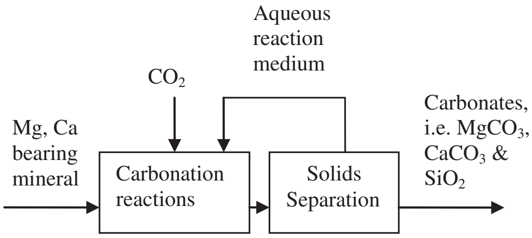

Fig. 1. Direct aqueous mineral carbonation.

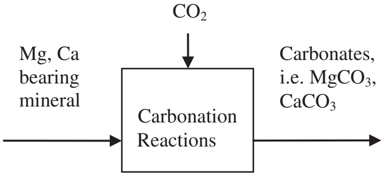

Fig. 2. Direct gas solid mineral carbonation.

Carbonation reaction between metal oxide bearing minerals with atmospheric CO_2 is a natural process that occurs spontaneously at low partial pressure and at ambient temperature, though this natural process is relatively slow. The idea of CO_2 sequestration by mineral carbonation came from this natural process that was first proposed by Seifritz [6], the first published study on this idea was in 1995 by Lackner et al. [7]. In mineral carbonation, CO_2 reacts with calcium (Ca) or magnesium (Mg) based natural silicate minerals and form naturally stable solid carbonated products. The most simple and straightforward carbonation reactions are,

$$\mathrm{CaO\ (s) + CO_2\ (g) \rightarrow CaCO_3\ (s)\ (Hr = -179\ kJ/mol)} \tag{1}$$

$$\mathrm{MgO\ (s) + CO_2\ (g) \rightarrow MgCO_3\ (s)\ (Hr = -118\ kJ/mol)} \tag{2}$$

This reaction produces higher exothermic energy as shown in the above reaction equation where heat values are given in all cases per unit mol of CO_2, though the reactant of this reactions, calcium and magnesium oxide is very rare in nature [7]. They are easily obtained from silicate minerals but produce less exothermic energy [7,8], for example,

$$\mathrm{CaSiO_3\ (s)\ (wollastonite) + CO_2\ (g) \rightarrow CaCO_3\ (s) + SiO_2\ (s)\ (Hr = -87\ kJ/mol)} \tag{3}$$

$$\mathrm{Mg_2SiO_4\ (s)\ (\mathit{Olivine}) + 2\ CO_2\ (g) \rightarrow 2MgCO_3\ (s) + SiO_2\ (s)\ (Hr = -90\ kJ/mol)} \tag{4}$$

Ca/Mg containing mineral ores (primary minerals) and industrial residues (secondary materials) are the main feed stocks for carbonation reaction, for example wollastonite ($CaSiO_3$), olivine (Mg_2SiO_4) and alkaline solid residues steel slag. Wollastonite is the most calcium-rich silicate mineral. Most research studies of carbonation technology have been done using serpentine, olivine and wollastonite due to their availability in nature [8]. Table 1 shows composition of some silicate minerals and their CO_2 sequestration capacity.

Research on carbonation technology has been carried out by the ‘mineral sequestration working group’ coordinated by the United States National Energy Technology Laboratory (NETL) and United States Department of Energy (DOE) and other participants of this group are Albany Research Centre, Los Alamos National Laboratory, Science Applications International Corporation (LANL) and Arizona State University [9]. Recently, a joint venture project has been established to setup a carbonation plant at Newcastle, Australia

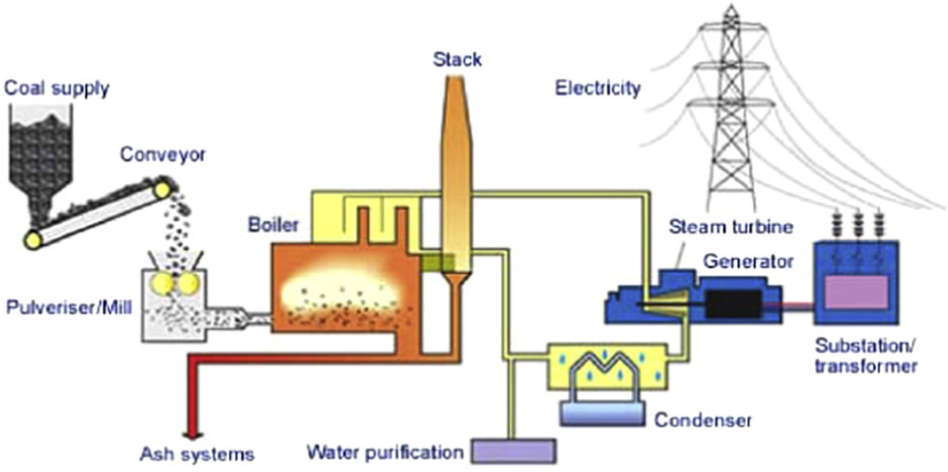

Fig. 3. Schematic diagram of a coal fired power plant [18].