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# LIFE CYCLE ASSESSMENT OF HIGH TEMPERATURE SORPTION OF $CO_2$ BY CARBONATE LOOP

**Kristína Zakuciová [1,2], Vladimír Kočí**

[1] University of Chemistry and Technology, Prague, Czech Republic
[2] Research Centre Rez, Husinec-Rez, Czech Republic

*Abstract*

*One of the long-term objectives of the environmental policy is to decrease the emissions of different kinds of industries. Research concerning $CO_2$ capture and storage (CCS) technologies takes place worldwide for many years, but the demand of current energy output has not yet been achieved by economically and technically manageable technology. The most common method of CCS technology is the capture of $CO_2$ from the flue gas after the combustion of fuel the so-called "post combustion" technology. An alternative method of post combustion technology is the high temperature sorption of $CO_2$ by carbonate loop. Life Cycle Assessment (LCA) of the carbonate loop contributes to the holistic view in terms of environmental burdens and benefits.*

*Keywords : Life Cycle Assessment, Carbonate loop.*

## 1 INTRODUCTION

The main goal of the environmental policy since 90's is to decrease the amount of greenhouse gases (GHGs) from different industrial sources. Agenda 20-20-20 EU set up the reduction of emissions by 20 percent in comparison to the emissions level in 1990's. This agenda is also achieving to increase the utilization of renewable sources in 20 percent, and an increase of the energetic efficiency in 20 percent. Another important objective is the achievement of a low carbon economy. The goal of this kind of economy is to integrate technologies with minimum GHGs production into all industrial sectors. In the frame of SET Plan (Strategy Energy Technology Plan), seven roadmaps were proposed to achieve the goals of low carbon economy. One of these plans is to achieve competitiveness of Carbon Capture and Storage (CCS) technologies [1]. Life cycle Assessment (LCA) is a suitable tool to assess such technologies. LCA studies are proposed in connection with a functional unit that describes the function of the whole system or technology. The functional unit for CCS can be the amount (in kilograms) of $CO_2$ captured. Although, the systems previously assessed were usually static without any dynamic changes in the amounts of semi-products. However, CCS systems belong to dynamic systems category, which require modelling in sequential cycles where products complement each other. Other interesting view is the weight of different environmental impact categories. The suitable method for this comparison in LCA is normalization. Normalization is defined by specifying equivalencies (e.g. per capita consumption in Europe). The equivalent value can represent an uncertain factor, which can be quantified based on a normal distribution with a standard deviation.

## 2 METHODOLOGY

Three capture and storage technologies are commonly known in a global energy research:

1. Post-combustion – the $CO_2$ is separated from the flue gas following the combustion
2. Pre-combustion – the $CO_2$ is separated from the flue gas following the gasification process
3. Oxyfuel –the fuel is burnt in oxygen rather than air and the combustion products are mainly $CO_2$ and water

Carbonate loop is uses the chemical sorption of $CO_2$ on a suitable sorbent by production of carbonates. Chemical sorption is operates in two subsequent processes:

1. Carbonation – takes place in the carbonate reactor with production of $CaCO_3$
2. Calcination – takes place in the calcinator with production of $CO_2$

Both reactions are described as follows:

$CaO (s) + CO_2(g) \longrightarrow CaCO_3 (s)$

$CaCO_3(s) \longrightarrow CaO (s) + CO_2 (g)$

## 3 LIFE CYCLE ASSESSMENT MODEL OF CARBONATE LOOP

LCA is commonly used for assessing and comparing technologies or systems which have the same function (e.g. carbon capture). Therefore, the functional unit is described as amount of $CO_2$ (in kilograms) captured by the technology. Two approaches were selected to model the carbonate loop:

1. Stoichiometric (ideal) model
2. Model with operational data

The first approach, is described in this paper, and is representing the ideal chemical reactions for carbon capture with 90 percent efficiency of $CO_2$ removal from flue gas. It is based only on the stoichiometric data and chemical reactions. One of the main requirements for the LCA is the set up the system boundaries. In the case of the carbonate loop, the boundaries include the process of carbonation and calcination, which are repeated in 10 cycles. This LCA kind of modeling required the division of the whole system into three plans:

1. Input plan – with all the input materials and energy
2. Intermediate plan– includes carbonation and calcination, where the values of data are the same in the flowing eight cycles
3. Output plan – includes output data as a waste heat and waste products and closes up the whole system.

These three plans are then connected through the reference flows. To make the whole stoichiometric LCA model logically balanced, there are some chemical assumptions accepted for every single plan.

The accepted assumptions for the input plan are in the following table.

**Tab. 1** Physical properties of input plan

| Physical properties | Values |
|---|---|
| Cp CaO | 763 J/kg/K |
| Cp $CaCO_3$ | 818 J/kg/K |
| $CO_2$ captured | 0.0396 kg |
| $CO_2$ from flue gas | 0.044kg /mol |
| CaO | 0.056kg/mol |
| Energy for carbonation | 0.0128 MJ |
| Energy for calcium carbonate decomposition | 0.176 MJ |
| Energy for calcium carbonate heat up | 0.05 MJ |
| Waste from calcium carbonate | 0.01 kg |
| Calcination heat | 2. 73 MJ |
| Reactive heat | 1. 76 MJ |
| $CaCO_3$ input amount | 0.1 kg |
| Temperature of input $CaCO_3$ | 8°C |
| Temperature of carbonation | 650°C |
| Temperature of calcination | 950°C |

The Intermediate cycle has the same values of physical properties, but the amount of calcium carbonate is 0,01 kg. It is 10 percent of the input amount of calcium carbonate. Subsequently, the energy for heating of 0,01kg $CaCO_3$ will be different – 0, 05 MJ. The output plan shows the total amount of waste as 100 percent of the input fresh calcium carbonate (0,1kg).

Primarily, carbonate loop should decrease the amount of $CO_2$ in flue gases. However, normalization function is performed in life cycle assessment (LCA) studies in order to better understand the relative significance of all impact categories. Normalization references are the characterized results of a reference system, typically a national or regional economy. Normalization is widely practiced in LCA-based decision support and policy analysis (e.g., LCA cases in municipal solid waste treatment technologies, renewable energy technologies, and environmentally preferable purchasing programs, etc [2]. The normalization was made for the whole carbonate loop technology in order to see the influences of the loop in all the impact categories. This function represents the weight of other impact categories rather than only global warming potential (GWP), which can significantly influence the environmental footprint of the whole technology.

## 4 RESULTS AND DISCUSSION

The stoichiometric model is based on chemical balances in order to clearly demonstrate the actual environmental effectiveness of the loop. Therefore, it is suitable to balance the model to the assumption of capturing 1kg $CO_2$ from flue gases. We divided the impact categories into two groups of GWP and other impact categories. This division was made due to focus on primary $CO_2$ reduction caused by the technology. Therefore, it is easier to calculate the environmental benefit. On the other hand, normalization can show environmental costs in other impact categories.

### Global Warming Potential (GWP)

The capture of 1kg $CO_2$ is showing the environmental benefit in the whole life cycle within the system boundaries in 66 percent. The main contributor that increases the output for GWP is the thermal energy utilization for reactive heat and heating up the calcium carbonate in the process of calcination. The production of thermal energy in the Czech Republic is mainly sourced from lignite, which results in high emissions of GHG. On the other hand, the thermal heat that is released from the high exothermic reaction of carbonation could be used for production of the electric energy. 33 percent of the waste thermal energy can be transferred into electric energy which is contributing to the environmental benefit in GWP category of 66 percent in the whole life cycle of the carbonate loop. If we would assume no further utilization of the waste heat, the effectiveness of the loop will decrease to 54 percent. The other option which could theoretically decrease the environmental burden is to use the waste heat as a source of thermal energy for heating. In this case, there will be less energy losses occurred and effectiveness of the whole system will increase.

### Other Impact Categories

As it was mentioned above, normalization function can demonstrate the different weight of the different impact categories rather than GWP. Among the all impact categories, abiotic fossil depletion has the highest output values. Values are shown up in the following graph.

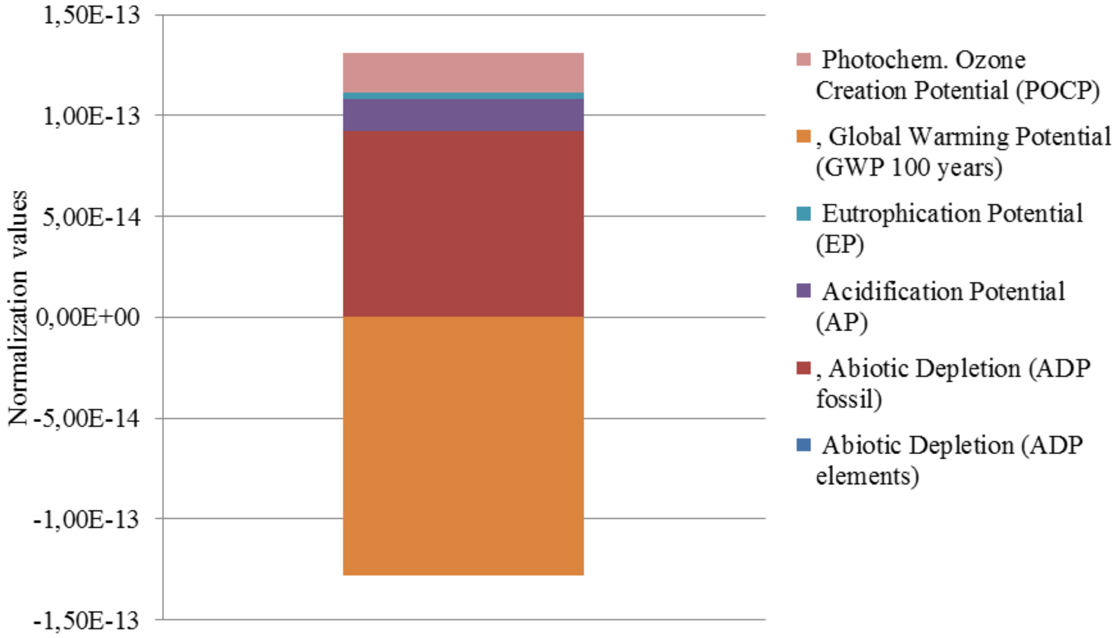


**Fig. 2** Environmental benefit and burden of carbonate loop in different impact categories after normalization

The graph shows the negative values after normalization, which actually represents a positive effect in GWP category (effectiveness of 66%). On the other hand, ADP category of utilization of fossils shows a positive value, which represents a negative impact in the whole life cycle of the loop. This result is connected with utilization of thermal energy as an input for the system. Thermal energy in the Czech energy mix is mainly produced from lignite (41.3 %). Therefore, the contribution to environmental burden is increasing. The dataset of production of heat from lignite includes technology mix and covers all relevant process steps and technologies along the supply chain. The lignite supply includes the whole supply chain of the energy carrier from the exploration, production, processing, and transport of the fuels to the heat plants.

LCA results can offer different options for improvement of the environmental profile of the system. One of the options, which can be considered, is the source of the heat for calcination process. In the sense that the Czech energetic mix uses lignite as the source of thermal energy it could be replaced by natural gas. The second suggestion is about the utilization of the waste heat. It can cause less energetic losses, if there was no transformation of thermal energy of steam to the electric energy. Heat can be directly used for the system's own heating without transformation and could increase the efficiency up to 90%. Finally, the uncertainty of physical parameters of chemical sorption can also influence the impact categories. For instance, heat capacities are uncertain in the range of the temperature of carbonation and calcination for $CaCO_3$ and CaO. Heat capacities are influenced by the temperature and the transition of temperatures from 8°C – 650°C- 950°C is relatively in a high range. The specification of the heat capacities is connected with gathering the data from actual operation of the loop which will be held in the further research.

## 5 CONCLUSION

LCA is a conceptual tool for modeling systems that are not yet in operation. LCA can predict the potential environmental impacts in various categories. The main benefit of the carbonate loop technology is the reduction of $CO_2$ present in flue gases. Potential efficiency of technology is counting with 90 % of $CO_2$ captured. Following the LCA way of thinking it is fundamental to include the environmental impacts of the whole life cycle including all energy and material inputs. The efficiency in the case of LCA evaluation decreases to 66%. The main reason is the utilization of thermal energy sourced from lignite, which is increasing values mainly in the environmental impact categories of abiotic fossils depletion. Another factor that can reduce the efficiency to of the loop to 54% is the non-use of the waste heat produced from the strong exothermic reaction of carbonation. The improvements that could be possibly implemented are following:

- Replacing lignite by natural gas as a source of heat.
- Direct utilization of waste-heat to the system's heating necessities (no transformation to electric energy).
- Precise determination of the heat capacities to ensure accurate model balance and results (representative of the practical process).

Carbon capture technology seems to be a promising technology for the actual $CO_2$ capture but it is necessary to look at the technology as a whole system with all up and down streams. It will be sufficient to assess carbonate loop in connection with the power plant. Then, the comparison of the systems with and without carbon capture could show the efficiency of the technology in an extended range. Another interesting study which will be further done is to compare different types of sorption for carbon capture technology as amine-based vs active-carbon $CO_2$. These studies can contribute significantly to understand and completely evaluate innovative systems that primarily help to decrease the overall environmental costs. It is a matter of data relevance and sensitivity analysis to perform the whole study in a correct and precise way, which will be done in further research.

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