Comparative Life-Cycle Assessment of Slurry and Wet accelerated carbonation of BOF slag

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Abstract

Accelerated carbonation is a CO₂ storage option, which allows to permanently fix CO₂ in a stable mineral form. Different natural Ca- and Mg-bearing materials can be used as source of alkalinity. These include minerals such as wollastonite, serpentine or olivine. Cement kiln dust (CKD), steelmaking slag (SS), fly ash (FA), air pollution control residues (APC), paper mill residues are some of industrial wastes that can be used as alkaline source. The advantage of using these industrial residues is their higher activity towards carbonation due to presence of alkaline-containing oxides and hydroxides, which reduces the effort need for extracting the reactive ions from the silicate matrix. Extraction and transport of the material can also be eliminated since these residues are usually generated at point source of CO₂ emissions.

Accelerated carbonation is typically performed using either direct or indirect routes. In the former, Ca or Mg dissolution and carbonates precipitation occur in the same unit, whereas in the latter the two steps take place consecutively in different units. Direct carbonation is typically carried out in a liquid/solid reaction medium and can be classified as slurry or wet route depending on the ratio between the solvent and the solid. For L/S > 1.5 l/kg the process falls under the slurry route category while processes with L/S < 1.5 are considered as wet route.

Recently, our group performed an assessment of accelerated carbonation processes for CO₂ storage using alkaline residues. Specifically, the material and energy requirements of both slurry and wet carbonation routes were evaluated and the influence of the properties of the residues (i.e. main mineralogy and particle size) and of the operating conditions (i.e. temperature, pressure and liquid/solid ratio) was analysed. The assessment was based on a dataset of slurry and wet carbonation experiments carried out on different types of alkaline residues, but specifically on Basic Oxygen Furnace slags, and allowed to assess the energy penalty associated to coupling accelerated carbonation to a power plant. A fair assessment of the accelerated carbonation routes shall anyhow take into account the overall impacts on the environment considering the whole life cycle of the processes.

In this work we performed a comparative Life Cycle Assessment (LCA) of slurry and wet route carbonation. As functional unit, we selected 1 MWh electricity produced from a natural gas fired power plant, which was considered more suitable for coupling to accelerated carbonation due to its lower specific carbon emissions. For the slurry route the process modelled with LCA included the following main unit operations: grinding of the residues; mixing with water to form the slurry; pumping of the slurry to the desired carbonation pressure; heating of the slurry by recovery of the hot slurry leaving the carbonation reactor; further heating of the slurry to the carbonation temperature;
CO₂ compression; mixing within the carbonation reactor. Besides, the treatment of the wastewater produced from the slurry phase reactor was also accounted for. For the simpler wet route the process modelled with LCA included again grinding of the residues to the desired size and CO₂ compression, whereas no heat recovery step was included. In both cases, transportation of steel slag to the carbonation plant and of the carbonated product to the landfill site and landfilling of the carbonated products obtained were considered.

The LCA was performed using the SimaPro software, relying on both foreground information obtained from our database and background information available in the software database. Each of the units were entered in SimaPro separately and independent of each other. Also, productions of the equipment were entered in SimaPro as separate processes and later as input into each process unit. Finally, to simulate the whole carbonation process, an assembly of the units was gathered to evaluate the life cycle of each carbonation route. The LCA methodology adopted was CML 2001, which includes the following mid-point categories: abiotic depletion, acification, ecotoxicity, eutrophication, global warming potential (GWP), human toxicity, ozone layer depletion and photochemical oxidation.

The obtained results showed that both routes are capable of storing CO₂ while providing a negative net contribution to global warming potential. However, the slurry route showed a higher reduction potential. Nevertheless, both routes gave a positive contribution to all the other environmental impact categories. In general wet route had approximately two times higher impact than the slurry route. One exception was the impact category of abiotic depletion, where the slurry route was observed to have the highest impact. The contributions to the mid-point categories were related mainly to the energy requirements. In the case of slurry route, mixing, compression, grinding and transportation were the main contributors in descending order, whereas for the wet route they were in the same order carbonation, compression, grinding and transportation.

By performing a sensitivity analysis, it was concluded that construction of the carbonation plant does not have a significant effect on GWP, while a dependency on transportation distance and electricity source was observed. Since the contribution in the other impact categories were mainly connected to electricity requirements, similar trends were observed.