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Reducing the cost of the post-combustion CO_2 capture applied to cement plant flue gas thanks to the heat integration with a CO_2 conversion process to synthetic natural gas

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Abstract

Considering that the industrial sector contributes to around one-third of the global CO_2 emissions worldwide [1], it is mandatory to reduce the implementation costs of technologies allowing to significantly decrease the industrial CO_2 emissions, such as Carbon Capture Utilization and/or Storage (CC(U)S). Focusing on the cement industry, one of the main CO_2-emitting sectors, the post-combustion CO_2 capture process using amine(s)-based solvents is the most mature technology currently available. However, reducing its costs (both CAPEX and OPEX) is still a challenge which needs process optimization and improvements, in particular to reduce the thermal energy needed for the solvent regeneration. In parallel, Power-to-Gas (PtG) process chains using renewable H_2 and captured CO_2 as feedstocks for producing e-fuels, like synthetic natural gas (SNG), are gaining interest as complementary solution to the geological storage of CO_2, especially when CO_2 transport infrastructures are not yet installed and/or CO_2 storage sites not available near the industrial plant. Such catalytic conversion of CO_2 into SNG is generally performed in a series of adiabatic fixed bed reactors [2], and this is an exothermal process leading to the release of large amounts of usable heat. Using this excess heat as thermal source for regenerating the solvent in a CO_2 capture unit is clearly an attractive option for avoiding the use of external thermal energy and therefore reducing the operating costs of the process.

Based on these elements, the present work investigates the Aspen Plus™ (V10.0) simulation of a post-combustion CO_2 capture process applied to cement flue gases (CO_2 content of around 20 mol.%, in comparison with 5 mol.% to 15 mol.% for power plants), and its energetical integration with a catalytic methanation process using renewable hydrogen. Considering a realistic scale of 10 MW for the electrolysis power (production of 180 kg/h of H_2 and conversion of 968 kg/h of captured CO_2), as illustrated on Fig. 1, three case studies were investigated for the use of the methanation excess heat: the production of electricity [2] usable by the CO_2 capture and the methanation units (Case 1), the capture of the maximum amount of CO_2 [3] leading to some extra-CO_2 compressed in view of transport for other CCUS applications (Case 2), and the generation of steam [4] that could be used by other processes in an industrial symbiosis vision (Case 3). It is worth mentioning that the raw-SNG upgrading for grid injection is out of scope of the present work as possible use of SNG directly on the industrial plant is envisaged (a 2-stages membranes-based upgrading process example is presented in [2]). Concerning the CO_2 capture unit (see Fig. 2), based on the configurations and solvents performances comparisons performed in [2,5], it includes a Rich Vapor Compression (RVC) configuration, combined with an Inter-Cooled Absorber (ICA) and two Water-Wash (WW) sections at the top of each column. The solvent is an activated blend composed of methyldiethanolamine (MDEA) 10 wt.% and piperazine (PZ) 30 wt.%. An absorption ratio of 90 % was assumed. All the technical details regarding the CO_2 capture and the methanation units are provided in [2–4].

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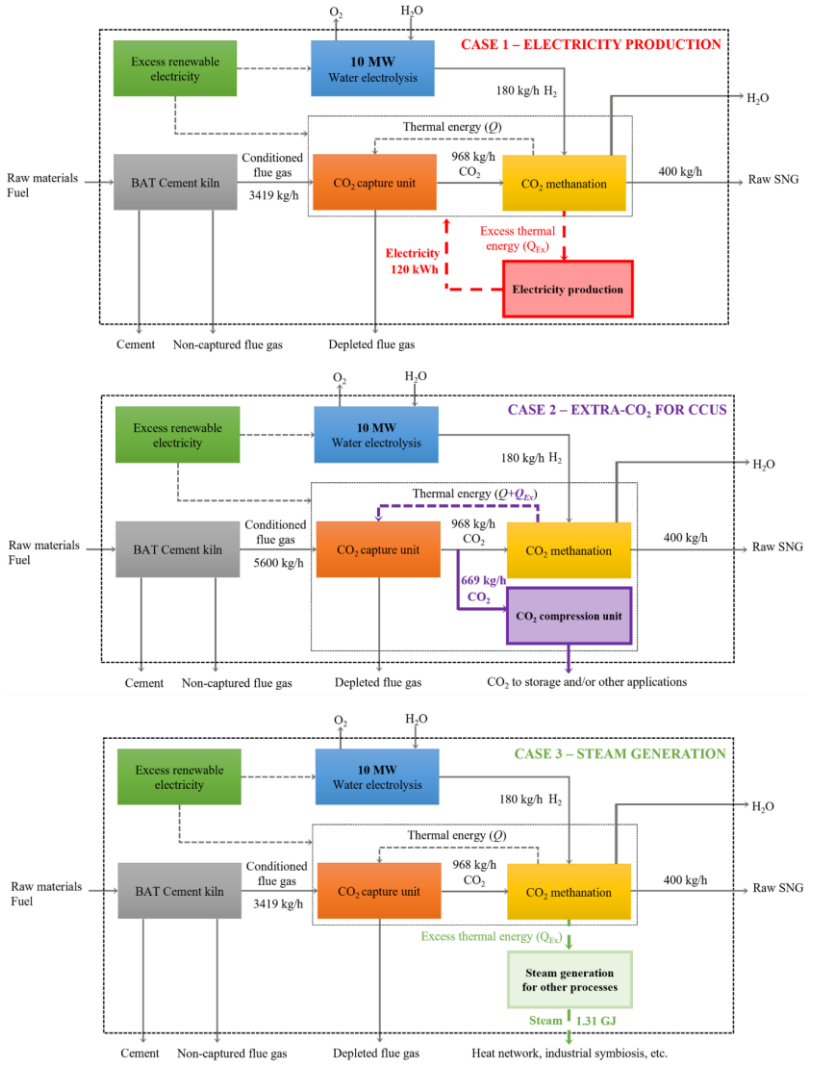

Fig. 1. Cases studies considered for the use of the excess thermal energy (Q_{Ex})

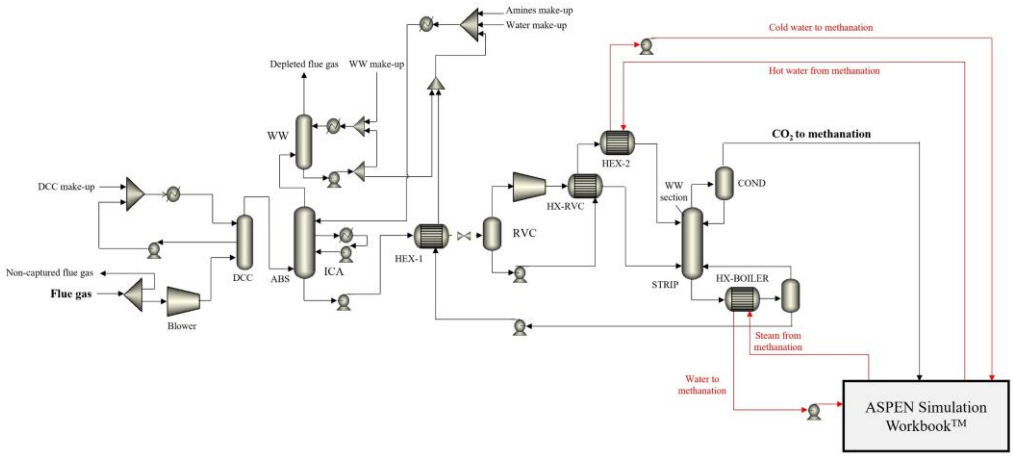

Fig. 2. Flowsheet of the CO_2 capture unit (with RVC, ICA and WW) energetically integrated with the CO_2 methanation process

Based on the simulation results, both techno-economic (TEA) and environmental (LCA) assessments were performed in order to quantify the economic and environmental interests of the proposed process chains.

Concerning the energetical results, it was shown that the implemented CO_2 capture process (RVC+ICA configuration and MDEA+PZ as solvent) leads to a Specific Reboiler Duty (SRD) of around 2 GJ/tCO_2. In addition to the configuration and solvent implemented, this low SRD value in comparison with literature ones (e.g. range of 2.3 to 3.9 GJ/tCO_2 in [6]) can be explained by the application to a cement plant flue gas (higher CO_2 content in the gas to treat in comparison with power plants, decreasing the SRD) but also by the double heat integration with the methanation unit. Indeed, as shown on Fig. 2, the hot water coming from the SNG production unit allows to give a complementary preheating to the solvent before entering the stripping column which leads also to a decrease of the SRD. Overall, in both cases, the CO_2 capture unit is self-sufficient in terms of thermal energy. Moreover, for example in Case 1, it was pointed out that in addition to the heat needed for the solvent regeneration, the electricity generated using the excess heat still available covers the entire electrical demand of the methanation unit, covering also 5% of the electricity demand of the CO_2 capture unit. On the other hand, in Case 2, the use of the entire excess heat for capturing the CO_2 allows to recover a supplementary flow of 669 kg/h of CO_2 for sequestration or other utilizations (almost 70% more than the quantity needed for the methanation unit). In Case 3, only 60% of the excess heat is used for the CO_2 capture, meaning that 40% is still available as steam for other purposes.

In terms of economics, one of the main observations is the fact that the supplementary CAPEX related to the heat integration (e.g. heat exchangers, pumps, etc.) represents only around 2% of the total CCU investment costs, while for example in Case 3 (total OPEX estimated to 117 €/tCO_2 without H_2 production) the OPEX would be 30% higher if external steam must be provided to the capture unit (without heat integration). For this Case, the OPEX and CAPEX breakdowns give a contribution of 44% related to the CO_2 capture unit and 54% to the methanation process. For the Case 2, a supplementary cost has to be considered for the CO_2 compression unit (same order of magnitude for CAPEX and OPEX as for the CO_2 capture unit itself).

Globally, the three Cases have shown an environmental interest. Different environmental impacts were investigated, including climate change (CC), fossil depletion, terrestrial acidification, freshwater eutrophication, human toxicity, water depletion, and metal/mineral depletion. Focusing on CC, in comparison with their respective reference scenario, the three approaches led to a relative decrease of the net CO_2 emissions higher than 70%. Nevertheless, the following specificities need to be considered: (i) the production of electricity needs either the establishment of, or to have access to, a high-pressure water network, as well as the implementation of a turbine, etc., which is not necessarily easy; (ii) the extra-CO_2 captured needs to fulfill the CO_2 transport network specificities in terms of purity (and such network must be available), and a potential other utilization or geological storage capacity of this CO_2 must be ensured; and finally (iii) the valorization of the excess thermal energy as steam is possible only if another industrial plant is situated not far from the cement plant itself in order to really perform an industrial symbiosis. For the three cases, it is also important to remind that the production of renewable H_2 remains an important factor for CCU, especially due to the high costs (both CAPEX and OPEX) of the electrolysis process, and also for the need of renewable electricity.

As next step of our work, the same methodologies presented in this communication could be potentially applied considering another post-combustion CO_2 capture process and/or another CO_2 conversion process.

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