WASTE TO ENERGY WITH CARBON CAPTURE VIA MOLTEN CARBONATE FUEL CELLS

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Waste-to-Energy (WTE) generates a significant reduction of the greenhouse gas emissions associated to waste treatment as a consequence of: i) displacement of fossil fuel-based electricity (and possibly heat); ii) recovery of metals from recycling; iii) avoided emissions of methane from landfill, which in many countries is still the dominant practise for waste disposal. WTE with Carbon Capture and Storage (CCS) would further improve the benefits of energy recovery from waste, making the process nearly carbon neutral – or possibly with negative equivalent CO_2 emissions.

This paper investigates technological challenges, configuration options, performances and costs of WTE plants retrofitted by Molten Carbonate Fuel Cells (MCFCs) placed downstream of flue gas treatment. The clean flue gas is fed to the cathode of the fuel cell, where CO_2 reacts with oxygen to generate carbonate ions; the $CO_3^{=}$ ions migrate to the anode, thereby generating an electric current and at the same time concentrating the CO_2 at the anode outlet. The process is driven by reformed natural gas fed to the anode inlet. The CO_2-rich flow exiting the anode is treated in a Gas Processing Unit (GPU) to remove the CO_2, while unconverted fuel left after CO_2 (and H_2O) removal can be used to generate additional steam (and therefore additional electricity) or possibly hydrogen for export. By properly selecting the size of the MCFC and adjusting its operating conditions, most of the CO_2 generated by the combustion of waste - as well as the CO_2 generated by the oxidation of natural gas - can be captured and made available for transport and permanent storage. In addition, passing the flue gases through the fuel cell cathode yields significant reductions of NOx emissions.

As a whole, the WTE+MCFC+GPU plant can be classified as a “hybrid” plant fed with waste and natural gas. The ratio between the amount of waste and natural gas to be fed to the plant depends on the configuration and the operating conditions of the MCFC, as well as the fraction of CO_2 to be captured. In this work we explore the configuration and the operation conditions most appealing for WTE applications, taking into account the need to bring down the concentration of impurities (SO_2, Hg and HCl) in the flue gases to very low levels to warrant the proper operation of the MCFC placed downstream. Such exploration is carried out by means of a software developed in-house at Politecnico di Milano and LEAP, which allows predicting the operating conditions and the mass/energy balances of the main plant components. The modelization of the fuel cell draws from interactions with the major world manufacturer of MCFCs.

The WTE section features configuration and operating parameters representative of state-of-the-art plants: grate combustion with integrated boiler; steam generated at 65 bar, 440°C; low-pressure feed-water heaters between the condenser and the deaerator, heat rejection by wet cooling towers, cogeneration by steam bleeding at 2 bar from the steam turbine cross-over, two-stage air preheating by steam bled from the turbine, etc. The MCFC system is inspired to post-combustion system arrangements considered in earlier studies, with its own Balance of Plant to ensure the pre-processing of all its input streams. The steam required for the pre-reforming reactions is generated internally by recovering heat from the hot streams exiting the cell module. The flows on the cathode and anode sides are maintained separate to avoid contact between any oxidant stream with a fuel stream. The natural gas and hydrogen stream used to supply the anode compartment and the catalytic oxidiser are pre-heated using the thermal content of the CO_2-rich stream at the anode outlet.

To give a feeling of the impact on the operation and performance of actual commercial plants, the modelization is developed for a specific case study: a 63 MW_{el} WTE plant located at the premises of Milan which generates both electricity and heat for district heating. For such state-of-the-art plant, integration with MCFCs allows capturing nearly 80% of the CO_2, increasing electric power output by approximately 100% and increasing thermal power for cogeneration of about 20%.

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