The role of hydrogen in the circular management of wastewater treatment plants

Hydrogenotrophic methanation process is an interesting solution to improve the sustainability of the biogas upgrading process in wastewater treatment plant. By using hydrogen as energy carrier, hydrogenotrophic methanogenesis ensures renewable energy production and the reduction of GHG emissions. ENEA carry out R&D activities aimed to implement circular management practices and sustainable technologies in wastewater sector, which allows the resource recovery from the sewage sludge treatment.

Il processo di metanazione idrogenotrofica è una interessante applicazione per migliorare la sostenibilità del processo di upgrading del biogas negli impianti di trattamento delle acque reflue. Attraverso lo sfruttamento dell'idrogeno come vettore energetico, la metanogenesi idrogenotrofica garantisce una produzione di energia rinnovabile la contestuale riduzione delle emissioni di gas serra. L'ENEA svolge attività di ricerca e sviluppo finalizzate all'implementazione di pratiche di gestione circolare negli impianti di depurazione e tecnologie sostenibili che consentono il recupero di risorse dal trattamento dei fanghi di depurazione.

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In Italy wastewater treatment sector is still largely based on dissipative models. Although generally complying with the effluent standards set by Italian legislation, the most of small-medium sewage treatment plants can be considered as energy-intensive infrastructures, lacking in technologies able to guarantee an adequate resource recovery during the various treatment steps, especially those applied for sludge treatment [1].
On the other hand, recent industrial and scientific developments in wastewater sector point out the potential to turn existing municipal wastewater treatment plants into strategic facilities, widely spread throughout the national territory, and able to provide efficient resources recovery through the interaction with several productive sectors, in accordance with the pillars of the circular economy [2].
Among the processes applied for sewage sludge treatment, the anaerobic digestion is adopted in most of large size wastewater treatment plants, aiming to the residual organic matter stabilization and ensuring at the same time renewable energy as biogas (approximately, 60% CH_4 and 40% CO_2) for *in situ* production of electricity and/or thermal energy. The amount of biogas produced from excess sludge digestion may ensure a significant contribution in the overall wastewater treatment energy and economic balance.
Nowadays, national energy policies encourage biomethane production from biogas upgrading and cleaning processes. The produced biomethane, once ensured the compliance with quality requirements fixed by the national regulation, can be exploited as a replacement or additional gas in transport and distribution networks.
Such approach, also involves further process efficiency measures aimed, on the one hand, at maximising the methane conversion yields

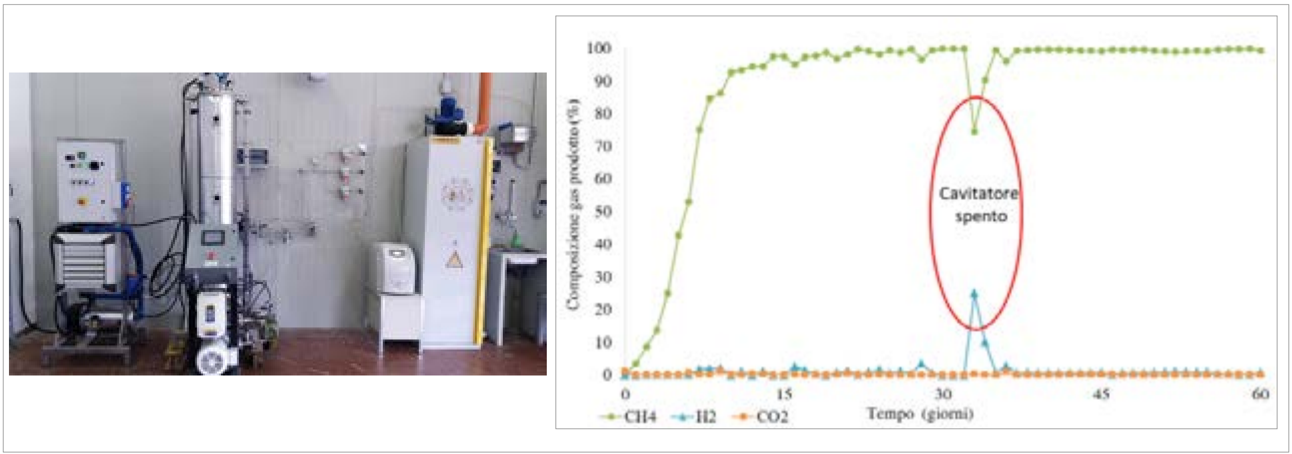

Fig.1 Hydrogenotrophic methanogenic reactor (1a – image on the left) and outlet gas composition (1b – chart on the right).

of sludge, e.g. through the inclusion of pre-treatment phases and, on the other hand, at ensuring a higher exploitation of the anaerobic digestion process due to the possible interaction with the waste management sector, e.g. through the co-digestion of sewage sludge with other biodegradable waste, such as the organic fraction of municipal solid waste (OFMSW) coming from separate collection. [4]
Among the opportunities to optimize the anaerobic digestion process in wastewater treatment facilities in terms of both energy efficiency and reduction of GHG emission, the application of processes involving the exploitation of hydrogen (H_2) as energy carrier for biomethane production represent a very interesting and promising option. Such approach provides a possible link between the wastewater treatment sector and the gas network as well the transport sector, representing an example of circular economy. Furthermore, this strategy is fully in line with the main drivers for technological development given by the current European policies (i.e. Green New Deal) which encourage the use of hydrogen gas as energy carrier to lead the transition towards carbon neutrality. [5]

The hydrogenotrophic methanation process

In this regard, one of the most interesting technologies is represented by the biological hydrogenotrophic methanation (BHM) process, based on the ability of some specialised microorganisms – present in the most extreme natural ecosystems characterised by high temperatures and the absence of oxygen – to use hydrogen to catalyse the conversion of carbon dioxide (CO_2) into biomethane (CH_4), which can be used to replace natural gas for a variety of end uses.
The BHM process can guarantee the capture and conversion of CO_2 flows into methane, representing an alternative to current upgrading technologies (based on chemical-physical processes and highly energy intensive) and being able to contribute to reduce GHC emission in accordance with national decarbonisation strategies.
Despite the relevant potential application, one of the main factor still limiting the large-scale application of the BHM process is given by the need to increase energy efficiency of the process, overcoming the technical barriers represented by the low hydrogen solubility in aqueous solutions and the consequent constraint to ensure its transfer to the hydrogenotrophic microorganisms present therein. [7]
The BHM for biogas upgrading to biomethane is one of the biotechnological process tested and developed by ENEA SSPT-USER-T4W (Laboratotory of technologies for efficent management of water and wastewater), which carries out R&D activity on material and energy recovery from urban and industrial wastewater.
The technical feasibility of the BHM coupled with an innovative gas-liquid mass transfer system based on controlled hydrodynamic cavitation (Figure 1a), was investigated in the framework of *+GAS project – Production of biomethane from renewable electricity* (http://www.piugas.enea.it/), funded by Emilia-Romagna Region (ERDF-ROP 2014-2020) and, subsequently, in the one of *Electrical System Research Project* (PTR 2019-2021), funded by the Italian Ministry of Economic Development.
The first experimental trials allowed to verify the technical feasibility to obtain a microbial biomass specialised in converting hydrogen and carbon dioxide into biomethane, starting from an inoculum taken from a full-scale anaerobic treatment plants. That was achieved without record any long-term inhibitory effect on hy-

drogenotrophic microorganisms due to the physical stress promoted by hydrodynamic cavitation, reaching conversion efficiency of hydrogen into methane of 0.20 $m^3CH_4/m^3\ H_2$, recording a stable CH_4 content higher than 98% in the gas produced from the bioreactor (Figure 1b).

Further process development to optimize the gas-liquid mass transfer step is required, in order to guarantee the overall energetic sustainability of this innovative process, towards its subsequent pre-industrial application.
required, in order to guarantee the overall energy sustainability of the process. Experimental tests are currently under way in this direction, with the goal of identifying technological solutions able to reduce energy consumptions related to the diffusion and transfer of gaseous fluxes in the liquid phase, and to be applied for subsequent pre-industrial developments.

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