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ADAPTATIVE GASIFICATION OF WASTE

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Abstract: *This work focuses on the adaptability to various contexts of a thermochemical process based on a technology object of a university-industry collaboration on demonstrative scale. The process is modular; that gives to the approach adaptative characteristics in terms of centralization and decentralization of the treatment. The flexibility of the process is based also on other aspects related to its modularity, that are analyses in details. The present preliminary analysis of the adaptability considers environmental, social and economic aspects in order to focus also on the sustainability of the approach in agreement with circular economy concepts.*
Key words: *circular economy; syngas; sustainability; waste management; waste-to-energy.*

1. INTRODUCTION

The sector of high temperature waste-to-energy options shows differences depending on geographical area, the kind of waste composition and environmental legislation [1][2][3][4][5][6]. What emerges from the sector is the need of flexibility for a waste management sustainability. Indeed, referring to the sector of Municipal Solid Waste (MSW), in the contexts where selective collection (SC) is growing, the amount and the characteristics of residual Municipal Solid Waste (RMSW) can change significantly during the lifespan of a waste-to-energy plant [7][8][9][10]. For instance, the amount of RMSW in an Italian region, that is the amount of MSW that could be sent to a high temperature waste-to-energy plant, changed from around 20% to around 80% in a couple of decades (that is the life span of a plant) [11]. Often, the conventional treatment for energy exploitation of RMSW is criticized because of its low ability to adapt to qualitative-quantitative variations of the input. There is a sort of competition with an increase of source separation activities when a plant has been already implemented. As pointed out, the amount of waste available for the input of a plant can change significantly, even if the economic development could increase the overall generation of MSW. The need of capacity treatment for special waste can change too during the years depending on the industrial development of an area and the implementation of waste prevention strategies. In this frame, the present work focuses on the adaptability to various contexts of a thermochemical process based on gasification [12][13] and object of a university-industry collaboration on demonstrative scale.

Gasification is defined as a high temperature thermochemical process where the needed oxygen is supplied under sub stoichiometric conditions, to generate a (combustible) syngas [14]. As reported in Fig. 1, the interest on it in the research sector is growing, even if incineration remains more investigated than gasification.

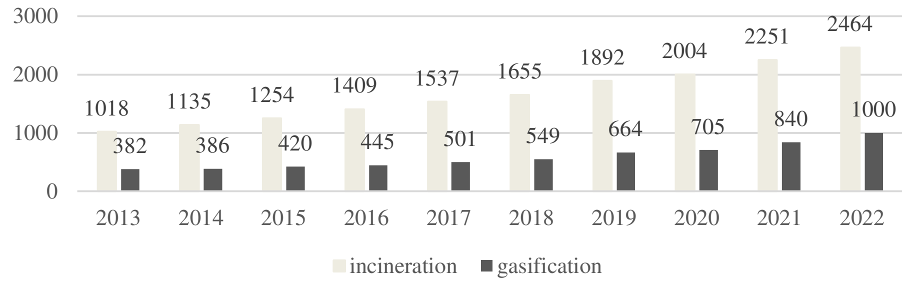

Fig. 1. Articles on waste in the Scopus® database

2. MATERIALS AND METHODS

The origin of the present work comes from the interest in exploring waste-to-energy approaches that could demonstrate potentialities beyond the limits of conventional solutions. The starting point of the analysis was the selection of a waste gasification process with unconventional characteristics [13][14][15][16]. In this frame, the attention focused on solutions showing a modularity in the structure of the plant to verify if the waste-to-energy sector could have traces of the evolution seen in the sector of composting, moved to modular plants a few years ago. An enhanced modularity is not yet common in the gasification sector but, in the present case, the advantage was to have access to an unconventional modular plant, at demonstrative scale, recently authorized in Italy. Even if the selected technology presents specific characteristics (that will be discussed in the result section) its classification can belong to the gasification field.

The analysis was performed, considering the following issues:

- Waste catchment basin;
- Capacity adaptability;
- Process adaptability to the input;
- Energy exploitability;
- Residues management;
- Environmental performances;
- Social acceptability;
- Economical aspects;
- Further process integrations.

These aspects include information suitable for a preliminary vision of the sustainability of the approach, that, as usual, consider environmental, social, and economic aspects.

3. RESULTS

After an analysis of the gasification sector and after seeking module-based technologies, this section reports the emerged characteristics of the selected process and the consequent discussion. The technology is Swiss [12][13] and seems to have in the extreme modularity a peculiar characteristic for the sector. That makes interesting to zoom on the previously listed items.

3.1 Waste catchment basin

The process is modular (a large plant could be based on tens of units): theoretically, the modules can be replicated up to the number suitable for the treatment of a target input of waste. That gives to the approach adaptative characteristics: both centralization and decentralization of the treatment are viable thanks to its scalability. This last one is not absolute as the process is based on the coupling of gasification modules and syngas combustion modules integrated with a boiler and a turbine that exploit the heat in the off gases (generated from the combustion of syngas). The combination of the two kinds of modules is optimized by the proposers according to their expertise: in practice, an X number of gasification modules is couples with and Y number of syngas combustion modules according to its expertise. However, as demonstrated by the technical literature, the choice of adopting gasification allows the implementation of plants with a lower capacity compared to the conventional process of direct combustion, more suitable for large plants (e.g. more than 100,000 t/y of treated waste, even if the threshold should be related to the power value too) [17].

3.2 Capacity adaptability

A part of the modules can be deactivated and moved to other sites when the availability of the input decreases steadily; of course, this flexibility is not absolute as it must be based on many factors: residual lifespan of a module, energy recovery design characteristics, distance of transport, etc. However, this characteristics seems to give an answer to a typical request that emerges during the discussion of the dimensioning criteria of a waste-to-energy plant: if a facility is designed to valorise the residual MSW in an area with near zero demographic development and source separation in evolution towards high rates, during the years that facility could result over dimensioned showing criticalities in terms of economic sustainability (that happens if import of waste generated in areas far from the plant is avoided). On the contrary, an approach based on modules can open to an adaptative management of the facility.

3.3 Process adaptability to the input

Each module is operated according to a batch feeding. Thus, each one can be regulated independently (temperature, retention time) for optimizing the thermochemical process in function of the characteristics of the input. In practice, in a conventional combustion like the direct one, the waste must adapt to the process thanks to a strategic mixing in the waste pit that receives it from the territory; by this solution, the input is made as homogeneous as possible. The approach from the adaptative gasification process can be considered as the opposite: the modules can be operated to allow gasification to evolve depending on the characteristics of the waste to be treated. This characteristic could give a solid output different from continuous fed gasification plants, as discussed in a following section.

3.4 Energy exploitability

In general, when gasification is performed, the syngas generated can be valorised depending on the local opportunities [18][19][20]. The conventional valorisation is based on the principle of co-generation (electricity generation and heat exploitation). Other alternatives depend on the effort in treating syngas for specific uses. In this frame, an interesting opportunity concerns the integration of existing district heating (civil and/or industrial) with a waste-to-energy plant. The composition of MSW (and some kinds of special waste that could be co-treated) presents a percentage of biomass-like mass that varies case by case (even higher than 50% in some contexts [21]). Supposing to have an existing natural gas-based district heating, the integration with the waste-to-energy plant could allow a partial substitution of a fossil fuel with a partially renewable energy source (waste). That could help a country to go towards a reduction of CO_2 equivalent emissions. The plant object of the present analysis has the advantage to allow an integration also in case of small existing district heating grids because of the possibility to implement gasification at small scale. In case of maintenance of the gasifier, the district heating can fully operate thanks to a full exploitation of the already existing installations based on natural gas.

3.5 Residues management

Circular economy and waste management must be integrated and in concordance with the strategies for climate change and environmental pollution decrease [22-27]. The involved options can be the following ones:

- Separate collection systems and material recovery plants (mostly for glass, metals, plastics, paper, organic waste, etc.).
- Production plants exploiting the recovered products according to the principles of green economy (glass factories, steel industries, plastic product industries, paper mills, combined anaerobic digestion plants to produce biomethane, possibly CO_2 as technical gas, composting).
- Treatment plants for non-recoverable and dangerous waste. In this frame, also energy recovery plants (high temperature waste-to-energy plants).
- Final disposal plants (landfill).

Some considerations are necessary to understand priorities and integration (a) the described integrated management follows the priorities of the European Union leaving landfilling as the last step to be considered; that depends also on the fact that direct landfilling of residual MSW cannot be performed longer because of the impact of fugitive emissions of methane generated by uncontrolled anaerobic digestion; thus, landfilling with a compulsory pre-treatment to avoid emissions of methane becomes an expensive option; (b) every treatment generates residues; thus, the presence of a waste-to-energy plant to treat them could avoid landfilling of those streams if they contain combustible fractions.

Incombustible materials present in the input of a plant can be recycled according to the principles of circular economy. Two aspects should be considered:

- Direct combustion gives residues that comes from a thermal stress at a temperature of 850°C or more. That makes bottom ash compatible with recycling in the sector of inert products, apart from some metals recoverable as still present in the waste.
- The gasification process of the analysed technology is performed at a temperature in the lower range of the values typical for this option. The operation of the first module is performed at around 300°C for most of the lasting of the treatment (of course, dealing with a batch system, a pre-heating is needed). That limits the thermal stress on the materials and could open to different perspectives of recycling.

3.6 Environmental performances

The environmental impact of a waste-to-energy plant must be seen in terms both of local and of global effects. The first one concerns the emission of micro and macro pollutants from the stack. The second one concern the emission of carbon dioxide (CO_2) generated from fossil fuels and equivalent CO_2 from other greenhouse gases released (e.g. N_2O). The best way of managing emissions giving local impact is to prevent their generation, when possible. Conventional solutions refer to direct combustion of waste. In areas like the European Union the regulation for emissions at the stack evolved significantly in the last decades. Thus, recent plants can reach important performances in terms of inhibition of pollutant generation like dioxins and furans (PCDD/F). That was obtained through a series of measure, as:

- Combustion temperature higher than a threshold.
- Permanence of the combustion gases in controlled chambers higher than a threshold.
- Geometrical optimization of the combustion chamber.
- Partial recycling of the off-gas to regulate the O_2 concentration during the combustion.
- Control of the homogeneity of temperature in the area of waste burning (specifically on the surface of a grate in case of such systems).

Following that, redundant solutions of PCDD/F removal have been optimized, like:

- Use of activated carbon
- Selective catalytic (or non-catalytic) reduction of NOx (with effects also on the PCDD/F concentration downstream the devices).

A part of this complex approach remains also visible in gasification plants. However, the process of gasification has an important characteristic: the sub stoichiometric conditions allow an inhibition of PCDD/F generation [28][29][30]. An additional advantage comes from the side of NOx emissions. The generation of syngas in place of off-gas allows optimizing the combustion of a gas in place of a solid. That allows a sort of limitation in the generation of NOx.

From the point of view of CO_2 emission role, the expected results of a comparison between direct combustion (incineration) and gasification followed by syngas combustion cannot be generalized. Indeed, a complete analysis must involve both the emissions generated for the construction of the plant and the avoided emissions related to the generation of electricity and heat for district heating: different amount of such kinds of energies because of different efficiencies of the technologies makes it necessary a detailed calculation also involving the effects of the power of the plant.

In this frame, a particularity of decentralized gasification must be pointed out: this approach allows to have lower waste transport pathways because of the construction of small plants, thus giving lower fuel consumption by the trucks.

3.7 Social acceptability

The potentialities of gasification can be listed as follows: (a) clear prevention of the formation of the most feared pollutant among the population (PCDD/F); (b) treatment capacity of the plants more acceptable from the public opinion: a small plant treats "your" waste limiting the arrival of waste from external regions. Of course, the concept of "external" area of origin is subjective; however, often the opposition refers to the arrival of waste from regions administratively external to the one that can authorize the plant.

Moreover, the specific technology analysed in this work presents a characteristic that, when confirmed, gives an answer to an important request, often used as an opposition key factor: conventional direct combustion of waste generates two kinds of residue, one from the bottom of the combustion chamber (bottom ash, typically not hazardous) and the other from the treatment of the off-gas (flyash, in case of dry treatment, typically hazardous). The presence of hazardous flyash at the exit of a plant that could have zero hazardous waste at the inlet is a sort of contradiction. According to the technical documentation at the base of authorization of the demonstrative plant in Italy [12], the technology analysed in the present work avoids the generation of two streams of ash aiming at generating only one, not hazardous. That could be a key factor for a change of paradigm and the acceptability of the plant.

3.8 Economical aspects

Some considerations could be useful to understand the particularity of the analysed technology:

- Transport costs for waste delivery when the plant is operating could be reduced thanks to the decentralization of the treatment (in case small scale were chosen as alternative to a large centralized plant).
- An easy transportation could come from the clear modularity of the components of the plant.
- Timing for the implementation of the plant could take advantage from its modularity when it must be produced (the same unit is replicated until the needed number of components is reached, without the need of re-design the core of the plant).
- Dismantling costs at the plant end of life can be reduced thanks to its modularity. This is a typical problem in the sector of waste as many old plants remain as a wreck for years because of the difficulty of getting the needed money and the complexity of the disassembling operations.

3.9 Further process integrations

Some considerations could be useful to understand the particularity of the analysed technology: (a) as consequence of the relatively low temperature of the process, residue valorisation could be different from a conventional approach; (b) heat exploitation in industrial plants could open to interesting options thanks to the possibility of integrating tailor-made facilities.

A process integration (self-supported thermal drying as pre-treatment) is going to be completed in Romania with a co-financing of European Union Structural Funds concerning sewage sludge final treatment [31]. More in general, the exportability of the approach depends on the local economic context, on the regulations in force and on the strategies that a country decides to perform. Waste-to-energy is not compulsory but can help in a frame of modern waste management and economic sustainability. The modularity of the analysed technology simplifies the organisation of plants implementation.

4. CONCLUSION

This article points out on a new vision of the waste-to-energy option based not only on the advantage to implement plants with a capacity lower than usual, but also on the high modularity of the technology, not yet exploited at this level in the sector of waste-to-energy. On the contrary, biological treatments as composting has opened to modular approaches since a few decades ago. An additional original characteristic is the different way of generating residues (ash). The expected output of incombustible material is only one and not two as in conventional plants. he authorized tests to be performed with an external independent validation of the environmental and efficiency of the plant, scheduled in Italy, will be useful to disseminate additional information of scientific origin. Finally, it is important to remember that waste to energy is seen in the European Union in a priority scale after material recovery. Thus, its implementation must be well integrated in an overall optimized management of waste. Exportability of a modular gasification has the potential advantage of simplifying its implementation.

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Gazificarea adaptabilă deșeurilor

Lucrarea de față se concentrează pe adaptabilitatea la diverse contexte a unui proces termochimic dezvoltat in cadrul unei colaborări universitate-industrie la scară demonstrativă. Procesul este modular conferind abordării caracteristice adaptabile în ceea ce privește centralizarea și descentralizarea tratamentului. Flexibilitatea procesului se bazează și pe alte aspecte legate de modularitate acestuia care sunt analizate în detaliu. In aceasta lucrare se prezinta o analiză preliminară a adaptabilității propunerii ținând cont de aspectele de mediu, sociale și economice in acord cu abordarea durabilă si cu conceptele economiei circulare.

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