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A techno-economic evaluation of a small-scale fluidized bed gasifier for solid recovered fuel

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ABSTRACT

This paper reports a technical assessment for an air gasification plant for energy recovery from 5000 t/y of a solid recovered fuel (SRF). This was obtained as one of the output streams from a sorting platform of municipal solid waste, which aims to minimize the utilization of the annexed landfill. The case study analysis was based on data provided by a pilot-scale bubbling fluidized bed gasifier, having a feedstock capacity of about 70 kg/h of the obtained SRF. The tests indicate that the SRF can be converted into a syngas of valuable quality for energy applications. A plant configuration, which includes a bubbling fluidized bed reactor, a mild combustor, a 400 kWe Organic Rankine Cycle generator and an air pollution control system, was defined and described in detail. The standard accounting items related to investment and operating costs were estimated on the basis of official manufacturer's specifications and information: they indicate an economic sustainability only in presence of an incentive tariff for energy production. A material flow analysis indicates that the implementation of the small-scale gasifier could allow a landfill volume saving of more than 10,000 m^3/y.

1. Introduction and framework

Municipal solid waste (MSW) contains remarkable amounts of materials, mainly derived from packaging, which can efficiently be recycled for a sustainable recovery of resources [1,2]. Recycling processes very often ensure a remarkable saving of primary resources, a strong reduction of amounts of wastes to be disposed, and a huge limitation of emissions arising during primary productions [3]. On the other hand, recycling is not always a fully sustainable process: all the waste recycling processes need materials and energy and generate residues; not all the materials can be efficiently recycled, i.e., without excessive consumption of resources; and only few materials can be recycled for many times. This simply means that recycling, as any other single waste management practice, is not suitable for all waste streams [4]. A modern integrated management system will be really sustainable if it includes effective waste prevention programs, good source separation practices, all the possible recycling activities not entailing excessive consumption of resources, efficient biological treatments of organic fractions as well as energy recovery processes from materials that cannot be efficiently recycled [3,5,6]. In particular, the large stream of the dry organic fraction of MSW that cannot conveniently be recycled or biologically treated, together with the high heating value residues from specific recycling chains, as those of paper and plastics, can be both processed into solid recovered fuel [7,8]. SRF is a sufficiently homogeneous fuel intended for use in an energy recovery facility, having composition and characteristics defined by a European standardization [9].

A sustainable process for thermochemical exploitation of SRFs is gasification in fluidized bed reactors. Gasification converts solid fuels to a synthesis-gas through a series of heterogeneous and homogeneous phase, gas-forming reactions, occurring in presence of an amount of oxidant strongly lower than that required for the stoichiometric combustion [10,11]. The resulting syngas is a fuel gas that contains large amounts of not completely oxidized products (mainly CO, H_2 and lower contents of CH_4), together with different organic (tar) and inorganic (H_2S, HCl, NH_3, HCN and alkali metals) impurities and particulates. Fluidization is a very promising gasification technology due to the high-quality gas–solid contact and the very efficient mass and heat transfers. Its intrinsic process flexibility is able to accommodate variations in fuel quality, to allow the utilization of different fluidizing agents, reactor temperatures and gas residence times, to add reagents along the reactor height and finally to operate with or without a specific catalyst [12]. Today, there is a great interest for SRF gasification for energy production, mainly from small- and medium-scale plants [13–15], even though a very large-scale fluidized bed plant has been recently put in operation in Finland [16].

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The paper describes the results of a research program aimed at assessing the technical and economic feasibility of a fluidized bed gasifier able to treat a mass flow rate of about 5000 t/y of SRF. The fuel is obtained as one of the output solid streams from a sorting platform of MSW collected in an urban area of Molise, in the middle of Italy. The unit produces the following: (i) different streams of plastics, ferrous and non-ferrous metals, which are sent to the market; (ii) a wet biodegradable fraction, which is composted and utilized in-situ as capping material for the annexed landfill; and (iii) a large stream of out-of-target materials, characterized by high calorific value, which is classified as an SRF and can be fed into a fluidized bed gasification plant for energy generation. This combination of processes and technologies, where the proposed SRF gasifier can be included, is schematically represented in Fig. 1: the final aim is to limit the mass flow of waste sent to the ultimate disposal and then optimize the utilization of landfill space. A number of tests were carried out by feeding the SRF in a pilot-scale bubbling fluidized bed gasifier (BFBG) in order to obtain data for a reliable technical evaluation. The experimental results were processed to obtain data and information useful to define appropriate design solutions and a suitable plant configuration for a technical and environmental practicable energy generation. Finally, an evaluation of main economic parameters was developed on the basis of official specifications and information of plant manufacturers.

2. The pilot-scale reactor and the tested SRF

The pilot-scale bubbling fluidized bed gasifier has a feedstock capacity of 70 kg/h of the selected SRF and a maximum thermal output of about 400 kW. Its main design and operating parameters are summarized in Table 1. It is noteworthy that the size of the reactor, which has an internal diameter of 0.381 m, is sufficiently large to avoid remarkable scale-up effects. Thereby, the results of experimental activity can be utilized to estimate the composition and the specific yield of the produced syngas in larger commercial facilities, as already made in previous studies [17,18]. The configuration of the experimental facility can be deduced by the quantified flow sheet of Fig. 2, which reports the mass flow rate (in kg/h) of the gaseous and solid streams under a specific operating condition. In particular, the stream of the bottom ash extracted from the gasifier is not reported since a test run was never longer than few hours and the accumulation of ash inside the bed is consequently limited (its flow rate for the specific test is 6.55 kg/h as reported in the diagram). For longer test runs, the bottom ash is extracted periodically by means of a pipe located in the middle of fluidizing gas distributor and equipped with a bayonet valve. A more detailed description of the pilot-scale gasification plant and its experimental procedures can be found in [15]. Here it is important to highlight that, under the selected operating values of equivalence ratio ER (defined as the ratio between the oxygen content of air supply and that required for the stoichiometric complete combustion of the fuel effectively fed to the reactor) and air preheating temperature, the reactor was always operated under conditions of thermal and chemical steady state, and without any thermal assistance of external heaters [15]. In other words, all the tests were carried out under autothermal conditions, i.e., the same under which the reactor will be operated in the real plant. It is also noteworthy that, taking into account the relevance of these measurements for the technical and economic feasibility of the process, two methods were used to evaluate the amount and composition of tar. The first, conservative method was utilized for quantitative determination of tar concentration in the obtained producer gas: it assumes that tar is composed

Table 1
Main design and operating parameters of the pilot-scale BFB gasifier.

Geometrical parameters	Internal diameter: 0.381 m, total height: 5.90 m, reactive zone height: 4.64 m, wall thickness: 12.7 mm
Feedstock capacity	Up to 70 kg/h (with the selected SRF)
Thermal output	Up to about 400 kW
Typical bed amount	145 kg
Oxidizing agent	Air
Feeding system	Over-bed water-cooled screw feeder
Range of bed temperatures	700–950 °C
Produced gas treatments	Cyclone, scrubber, flare
Safety equipments	Water seal, safety valves, rupture disks, alarms, nitrogen line for safety inerting

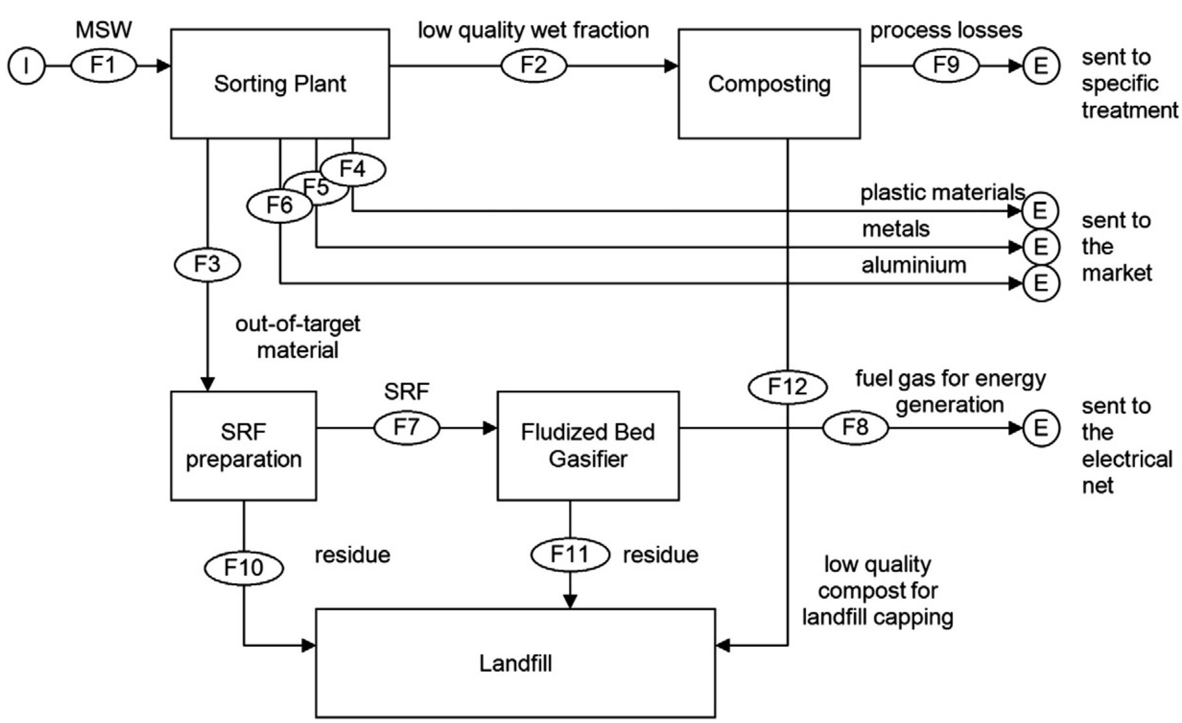

Fig. 1. Schematic of the proposed waste management system where the energy generation in a fluidized bed gasifier of SRF can be included. I = input stream; E = output stream; $i = 1–12$ indicates the different solid streams.