



Gasification of a solid recovered fuel in a pilot scale fluidized bed reactor



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HIGHLIGHTS

- Pilot-scale investigation of fluidized bed gasification of a solid recovered fuel.
- Tests under conditions of thermal/chemical steady state at various equivalence ratios.
- Complete composition of the syngas, including tar, particulate and acid/basic gases.
- Tar characterization according to the ECN classification.
- Partitioning of main inorganic elements in the entrained fines and bed particles.

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ABSTRACT

The paper investigates the technical feasibility of an air gasification process of a Solid Recovered Fuel (SRF) obtained from municipal solid waste. A pilot scale bubbling fluidized bed gasifier, having a feed-stock capacity of about 70 kg/h and a maximum thermal output of about 400 kW, provided the experimental data: the complete composition of the syngas (including the tar, particulate and acid/basic gas contents), the chemical and physical characterization of the bed material and that of entrained fines collected at the cyclone. The experimental runs were carried out by reaching a condition of thermal and chemical steady state under values of equivalence ratio ranging from 0.25 to 0.33. The results indicate that the selected SRF can be conveniently gasified, yielding a syngas of valuable quality for energy applications. The rather high content of tar in the syngas indicates that the more appropriate plant configuration should be that of a “thermal gasifier”, with the direct combustion of the syngas in a burner ad hoc designed, coupled with an adequate energy-conversion device.

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1. Introduction and framework

The amount of the municipal solid waste (MSW) increases all over the world as a consequence of growing urbanization and the standard of living. A recent study indicates that urban areas consume about 75% of natural resources and produce 50% of the total amount of waste in the world [1]. A remarkable amount of this waste contains materials (such as paper, glass, metals, wood and plastics), mainly deriving from packaging, which can efficiently be recycled for resource recovery. But not all the MSW can be recycled and, moreover, the waste recycling processes always generate significant amounts of residues, in some cases having very high heating values [2,3]. It is today recognized that in a fully sustainable waste management system no one process is suitable for all waste streams [4–8]. In other words, no single waste management

practice (i.e. landfill, recycling, biochemical or thermochemical conversion) can handle the full array of waste types and, at the same time, satisfy the recognized criteria of an integrated and sustainable management system [3,9]: (i) to minimize use of landfills and ensure that no landfilled waste is biologically active or contains mobile hazardous substances; (ii) to minimize operations that entail excessive consumption of raw materials and energy without yielding an overall environmental advantage; (iii) to maximize recovery of materials, albeit in respect of the previous point; and (iv) to maximize energy recovery for materials that cannot be efficiently recycled, in order to save both landfill volumes and fossil-fuel resources. With reference to the latter criterion, two remarkable waste streams have a great potential of being used in sustainable energy recovery processes: the unsorted residual waste (i.e. the dry organic fraction of MSW that cannot conveniently be recycled and it is not suitable for biological treatments) and the high heating value residues produced by some recycling chains (that in some countries cannot be landfilled [10]). These non-hazardous waste fractions can be turned into a Solid Recovered Fuel (SRF), i.e. in a sufficiently homogeneous waste-derived

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fuel, obtained as the result of a mechanical process to comply with a CEN standard [11]. The European standardization defines different grades of SRF on the basis of specific composition ranges, mainly low heating value and chlorine and mercury contents.

An efficient way for thermochemical exploitation of SRFs is fluidized bed gasification. Gasification is the conversion of solid fuel to a synthesis-gas through gas-forming reactions occurring in presence of an amount of oxidant lower than that required for the stoichiometric combustion. The resulting fuel gas (named “producer gas” or “syngas”) can be utilized in a separate energy conversion device: it contains large amounts of not completely oxidized products (mainly CO, H₂ and lower amounts of CH₄), together with different organic (tar) and inorganic (H₂S, HCl, NH₃, HCN, alkali metals) impurities and particulates [12]. Fluidization is one of the most interesting gasification technologies, mainly for the high quality of gas–solid contact and the very efficient mass and heat transfers, but also for its good process flexibility, which accommodates variation in fuel quality and allows to utilize different fluidizing agents, reactor temperatures and gas residence times, to add reagents along the reactor height and to operate with or without a specific catalyst. A large-scale fluidized bed gasifier has been recently put in operation in Lahti, southern Finland: it is able to treat 250 kt/y of SRF derived from household waste (origin sorted) together with industrial waste, demolition wood and waste wood from industry and to produce 50 MW of power and 90 MW of district heat [13]. But there is also a great interest for SRF gasification for energy production in small and medium scale fluidized bed plants [14–16].

The paper describes the results of a research program aimed at assessing the technical feasibility of a fluidized bed gasifier able to treat 5000 t/y of a SRF, obtained as one of the output solid streams of a sorting and mechanical treatment of MSW collected in a urban area of the Middle of Italy. To this aim, a number of tests with this SRF were carried out in a pilot scale bubbling fluidized bed gasifier (BFBG). The obtained experimental results were processed by mass and energy balances, in order to obtain data and information useful to define both a suitable plant configuration and the related design solutions for a fully sustainable energy generation.

2. The fluidized bed gasifier, the experimental procedures and the material tested

2.1. The fluidized bed gasifier

The design and operating parameters of the pilot scale bubbling fluidized bed gasifier are reported in Table 1. The plant has a feedstock capacity between 30 and 100 kg/h, depending on the type of fuel, and a maximum thermal output of about 400 kW. It is composed of three main sections, as it is sketched in Fig. 1: the feeding system, the fluidized bed gasifier and the syngas cleaning unit. The first can be divided in the blast and fuel feeding. The blast feeding is heated up to about 150 °C by a first electric heater, then sent to a mixing point with an optional stream of steam at about 150 °C, and finally heated by a second electric heater up to the desired inlet temperature at the fluidized bed bottom. In all the experiments reported here, only air was used as blast agent and always injected at the bed bottom while the fuel was always fed by means of an over-bed system. The gasification section is composed of a cylindrical reactor, 0.381 m ID and 5.90 m high, which is heated up to the reaction temperature by the sensible heat of pre-heated blast gases and by a set of three external electrical furnaces. The syngas cleaning section is composed of a high efficiency cyclone (for abatement of fine particles), a simple wet scrubber (for removal of tar, residual dust, acid gases and ammonia) and a flare.

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 100 kg/h (on the basis of the fuel heating value)
Thermal output	Up to about 400 kW
Typical bed amount	145 kg
Oxidizing agent	Air (but also oxygen, steam, and their mixtures)
Feeding system	Over-bed water-cooled screw feeder
Range of bed temperatures	700–950 °C
Range of fluidizing velocities	0.3–1 m/s
Produced gas treatments	Cyclone, scrubber, flare
Safety equipments	Water seal, safety valves, rupture disks, alarms, nitrogen line for safety inerting

2.2. The experimental procedures

Each run has a start-up of about 3 h, during which three electric heaters located along the reactor lead the temperature up to about 700 °C, while the bed is fluidized at a fixed velocity. At this point, the flow rates of SRF and air are adjusted in order to obtain the desired value of the 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. Under the selected operating conditions of ER and air preheating temperature, and without any more thermal assistance of external heaters, the reactor gradually reaches a thermal and chemical steady state. The gas and solids sampling procedures are then activated and measurements of pressure, temperature, blast flow rates and syngas composition upstream of and downstream of the wet scrubber are taken and averaged over the whole period of steady state, which usually is kept for about 2 h. Fig. 2 shows the successive steps of the described procedure, reporting the time profile of gas composition and bed temperature for a typical run.

In order to increase the reliability of measurements, in all the runs the composition of the syngas downstream of the cleaning section was on-line monitored by means of two systems: a series of IR analysers (Horiba VA-3115 for CO, CO₂ and O₂, Horiba VA-3001 for CH₄ and Teledyne Anal. Instr.-2000 for H₂) and an Agilent 3000 gas-chromatograph equipped with 4 different columns (Mol Sieve, PoraPlot, OV, Alumina) for the detection of a wide spectrum of syngas compounds. Gas was also sampled in Tedlar bags at two other points (2.3 m from the reactor bottom and the gasifier exit) and sent to off-line measurements. Two methods were used to evaluate the amount and composition of tar, due to the relevance of this measurements for the technical and economic feasibility of the process. The first assumes that tar is composed of all organic compounds with a molecular weight larger than benzene, excluding soot and char: then it conservatively imputes to the tar amount the whole carbon loading which, as a result of a mass balance on atomic species, cannot be attributed either to the producer gas or to the solids collected at the cyclone or present inside the bed. The second method samples the condensable species by means of a system composed of four in-series cooling coils, a suction pump and a flow meter operated with a syngas flow rate of about 300 dm³_N/h for 30 min: the condensed hydrocarbons are then off-line analyzed with a specific pre-treatment in a Perkin–Elmer Clarus 500 gas chromatograph coupled with a mass spectrometer (GC–MS). The first conservative method was utilized for quantitative determination of tar concentration in the obtained producer gas. The second procedure was instead used to detect tar

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