Modeling Oxy-Pyrolysis of Automotive Shredder Residue in a Rotary Kiln Converter Operated with Oxygen Staging

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Highlights

- A model of a rotary kiln oxy-pyrolyzer of waste derived fuels has been developed.
- Staged feeding enhances the quality of syngas promoting partial oxidation of tar.
- Results of model computation show good agreement with experimental data from pilot plant.

1. Introduction

Thermal conversion of waste-derived fuels is gaining a clear role in the general frame of the circular economy as one pathway to close the recycle loop. Even though the calorific value of these materials is generally lower than that of fossil fuels and the amount of pollutants (e.g., based on sulphur, chlorine, nitrogen) may be significant, their thermal conversion often provides a strong mitigation of disposal problems or answers to specific environmental legislations. Car fluff, a waste material resulting from the treatment of End Of Life vehicles (ELVs), is obtaining a growing interest due to the strict European Directive 2000/53/EC which sets to $5\%_{wt}$ the maximum weight of ELVs that can be disposed in landfill. More into detail car fluff, also known as Automotive Shredder Residue (ASR), is the non-ferrous residual fraction remaining after the operation of decontamination, dismantling, shredding of the hulk and recovery of metals performed on ELVs. It accounts for about $20\%_{wt}$ of the original ELVs weight, and it is a highly heterogeneous material. Its main components are plastics, rubber/elastomers, textiles, wood, paper, inerts and polyurethane foams. The relative fraction of these components can be very different according to the treated vehicles and to the specific strategy of material recovery applied. The presence of plastics, rubber and textiles confer a high calorific value to the car fluff, whose value ranges from 14 MJ/kg to 30 MJ/kg. The ash and moisture content ranges instead from 18% to 68% and from 0.7% to 26%, respectively [1–2].

2. Methods

The present study addresses gasification of car fluff in a Rotary Kiln (RK) converter. Gasification conditions are those relevant to oxy-pyrolysis, i.e. pyrolysis of the substrate fuel combined with in situ oxidation/reforming of volatile matter so as to: a) ensure autothermal operation of the system; b) tailor the composition of the produced syngas according to a prescribed reference composition. The RK reactor modeled in this work closely resembles a pilot-scale test facility designed, built and patented [3] by an Italian company known as C.S.M. The reactor is characterized by axially distributed O_2 feeding, with uneven distribution of the O_2 stream according to a prescribed axial profile. The conceptual model underlying the converter is the well-known Zwietering reactor paradigm. A scheme of the reactor is reported in Figure 1. It is characterized by an internal diameter of 0.9 m and a total length of 2.64 m; the gaseous oxidizing stream is fed through the use of 7 evenly spaced nozzles along the first 1.4 m of the reactor length. In this study the whole set of equations representative of the system, both governing and constitutive, have been derived including a purposely developed semi-lumped kinetic network. The model is based on mass and energy balance equations written on each phase, whose solution yields the axial profiles of species concentration and temperature along the reactor. The main focus of the study is the assessment of the effectiveness of axial staging of O_2 as a tool to control and minimize the generation of soot and condensed phases and to improve

the yields in valuable gas components. A comparison with data obtained from the operation of the pilot plant, in terms of outlet concentration of the major gaseous species, has been performed.

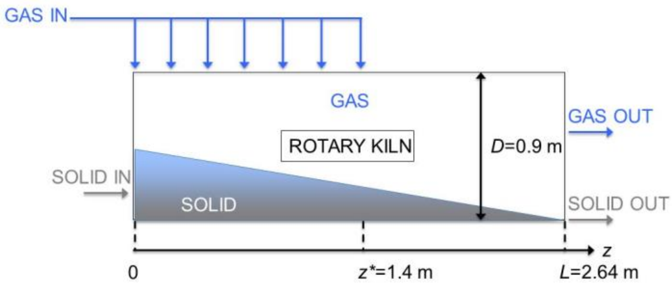

Figure 1. Scheme of the oxy-pyrolyzer reactor with distributed gas feeding.

3. Results and discussion

Figure 2-a reports the fluxes of the major gaseous species along the converter as obtained from model computations. H_2 and CO concentration increases in the feeding zone due to the combined effects of car fluff devolatilization and cracking+oxidation of the tar compounds. Their consumption by oxidation is only slight, as can be inferred by the H_2O and CO_2 profile, because most of O_2 is preferentially consumed by tar-related chemical reactions. The trend beyond the distributed feeding zone is instead mostly ascribed to the occurrence of the water-gas shift reaction. Figure 2-b reports the axial profiles of solid and gas temperatures. The wall temperature profile was obtained from experimental data on the operation of the C.S.M. pilot plant. The temperature of both solid and gas phase initially grows slowly (up to 0.6 m). Then, after the release of oxidable species from car fluff devolatilization, both the temperatures reach a high value as a consequence of the exothermic reactions occurring in the gas phase. Beyond the distributed feeding zone, the temperature decreases as no more O_2 is fed to the system. Overall, model computations predict the obtainment of syngas with calorific value of about 11 MJ/kg and with the following characteristic molar ratio: H_2:CO=0.8, CO:CO_2=2.9 and N_2:H_2=1.3. Predicted results in terms of outlet concentration are in good agreement with experimental data coming from the operation of the C.S.M. pilot plant.

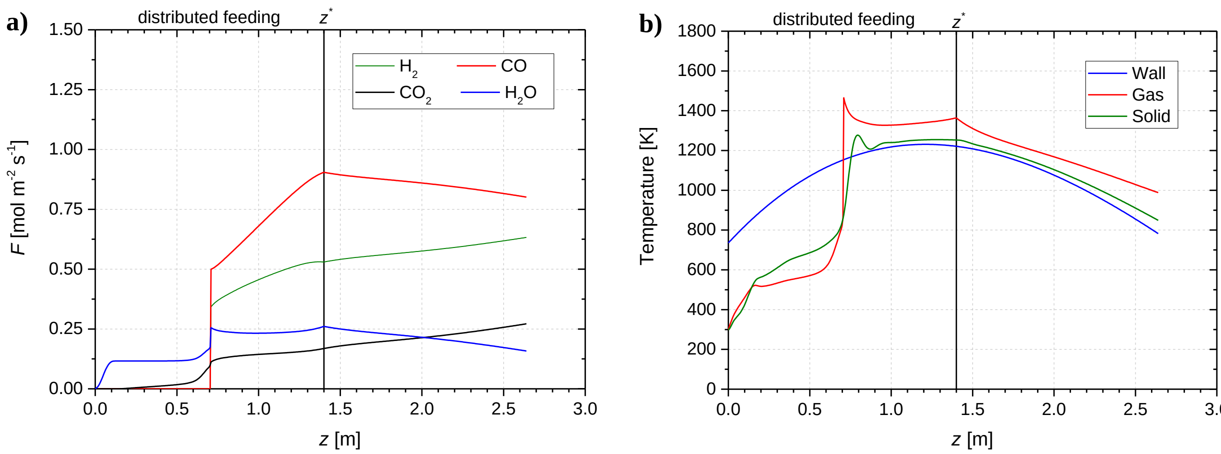

Figure 2. a) Fluxes of H_2, CO, CO_2, H_2O along the reactor; b) Temperature of solid, gas and wall along the reactor.

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Keywords
Car fluff; Modelling; Rotary kiln; Staging