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Modular Simulation and Optimization of an 12MW Industrial Gasifier

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Abstract

In this work, a flexible model, built from elementary modules, is developed for an industrial waste gasification process, in an industrial moving bed reactor located in Morcenx (France). This gasifier is able to treat more than 46,875 ton/year of RDF (Refused Derived Fuel) waste for producing 12 MW. Drying, pyrolysis, combustion / gasification and plasma polishing are used to convert waste directly into a synthesis gas composed of carbon monoxide and hydrogen. This synthesis gas is then used for producing electricity via gas engine.

Keywords: Modular Simulation, Gasifier, Optimization, Synthesis Gas

1. Introduction

The objective is to turn waste power potential into electricity with an environment friendly process. The gasifier is designed to treat 6.25 t/h of Refused Derived Fuel (RDF) waste for producing 12 MW. The three main steps of conversion of waste to gas and electricity are shown in figure 1.

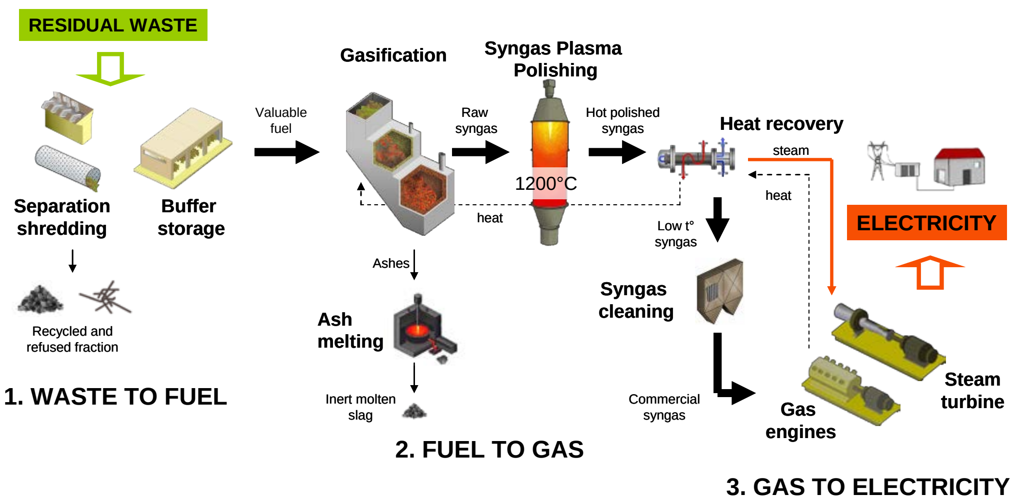

Figure 1: Main steps of the conversion of RDF waste to gas and electricity

We are interested in the second step of this scheme. Firstly the material system is briefly described. Then, the modeling approach of the three chambers of the gasifier is studied. Finally, some results on a case study, sensitivity analysis and conclusions are given.

2. Material system

The material system under consideration contains solids and gases. The main assumptions for modeling this material system are the following.

2.1. Solids

Three solids are considered in the model: the fuel part of the waste (FPW), the char and the ashes. The FPW constitutes the dry part of the waste, without ashes. It is defined from its atomic composition as an equivalent molecule: $CH_{\xi_1}O_{\xi_2}N_{\xi_3}S_{\xi_4}$. The fundamental property of RPW is its Inferior Heating Power (IHP). Although some correlations have been proposed for its estimation (Niessen, 2002, Higman and Van der Burgt, 2003, Riazzi, 2005, Pröll and Hofbauer, 2008, Antonini, 2003,) it is better to determine its value from experimental data. The char is the solid residue coming out pyrolysis. Its properties are assimilated to pure carbon. The percentage of carbon grows with the pyrolysis temperature and it is approximately 90% at 700°C (Nozahic, 2008). The soots are not taken into account. Finally, ashes that are the mineral part of the waste are taken into account only for mass and energy balances and are considered as chemically inert. The properties of ashes are assimilated to those of SiO_2

2.2. Gases

The gases under consideration are the following:

- O_2, N_2 for the air feedstreams (drying, combustion and decarbonation sections);
- Water for the waste and air moisture. Water is also a pyrolysis product;
- H_2, CO, CO_2 that are combustion/pyrolysis/gasification products;
- CH_4 is also a pyrolysis product.
- Tar is assimilated to a toluene/naphtalene mixture.

Some gaseous pollutants are also considered in this study: NO, NO_2, SO_2 and H_2S resulting from nitrogen and sulfur present in the waste.

3. Gasifier Modeling

The technology used by Europlasma for the waste gasification is confidential. It is a moving bed with three chambers. For modeling purposes, the gasifier is divided in five main sections, in agreement with the gasifier structure and the elementary physico-chemical phenomena. The schematic representation of the gasifier model with all elementary components is presented on figure 2. The sections are the following:

- Drying section (chamber 1) in which waste moisture is decreasing.

- Flash pyrolysis section (chamber 2.1). This first step of the waste thermochemical transformation produces a gaseous phase, containing carbon monoxide, carbon dioxide, methane, hydrogen and water but also pollutants and tar and a solid phase, the char.

- Combustion/gasification section (chamber 2.2) of the char. Combustion is exothermic and is the energy source for balancing the endothermicity of gasification and pyrolysis. The plug-dispersion flow of the waste inside the gasifier chamber 2 is represented by a series of perfect mixing reactors 2.2.i.

- Decarbonation section (chamber 3). In this last step, the residual char is almost totally gasified by supplementary air in order to respect environmental constraint of carbon content in waste ashes: mass fraction of C less than 3 %.

- All gases produced in the three previous sections (pyrolysis, combustion / gasification and decarbonation) are then collected in the main chamber of the gasifier (chamber 2.3) where gas phase reactions, such as water gas shift, are occurring.

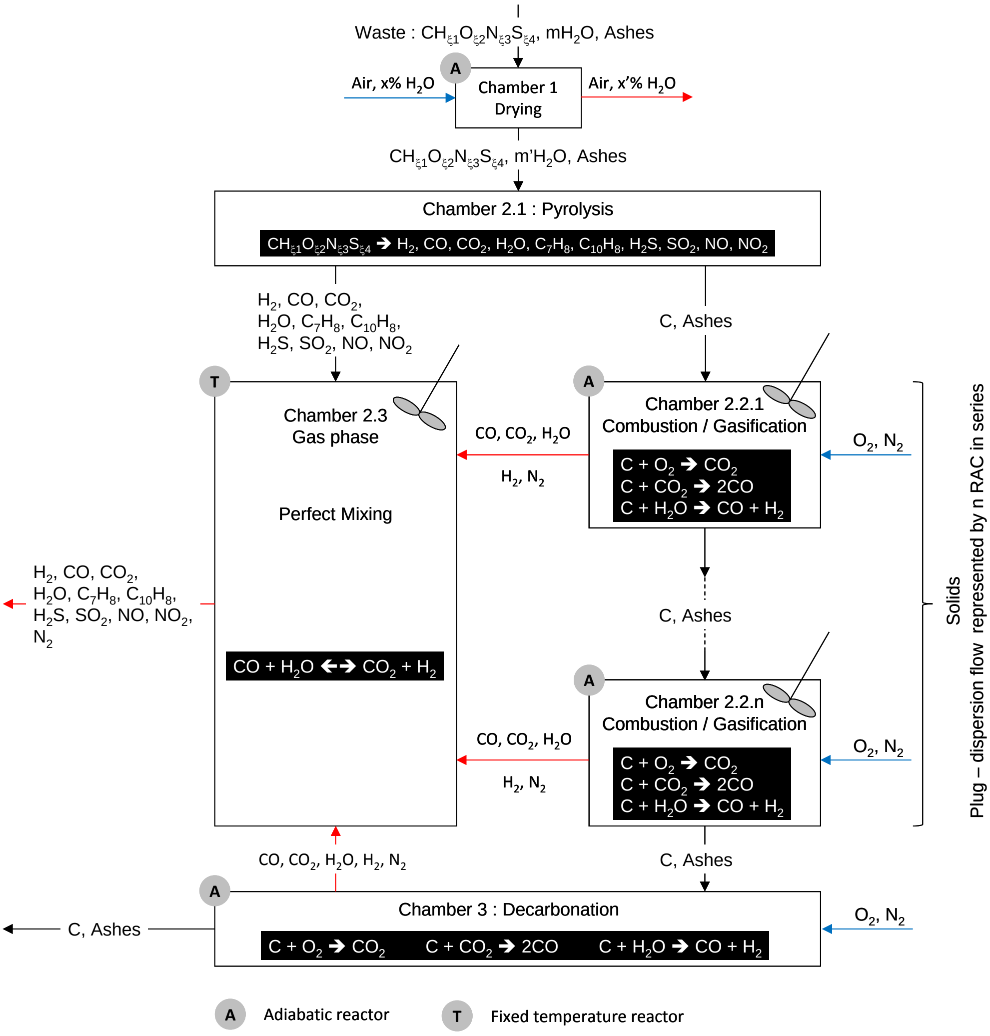

Figure 2: Schematic representation of the gasifier model

The two main assumptions of the model are the adiabaticity of the whole gasifier and the absence of cracking reactions. This last one is justified by the fact that, by using plasma technology, all organics are then transformed into CO/H_2 (see figure 1).

Each section model is built from elementary standard modules of the ProSimPlus® simulator. As illustration, figure 3 shows the simulation diagram of the chamber 2 where occur pyrolysis, combustion and gasification. The gasifier simulation diagram is obtainer by aggregation of the sub-diagrams.

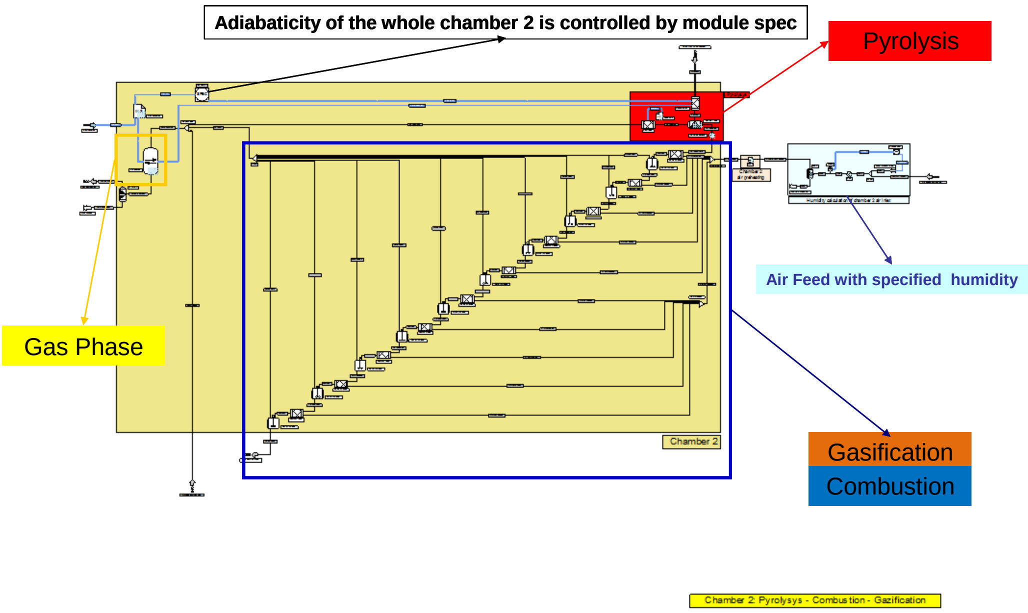

Figure 3: ProSimPlus® simulation diagram of the gasifier chamber 2

The model fundamental parameters concerns pyrolysis and are the ratio of pyrolysed carbon, τ, and the composition of the pyrolysis gas. These parameters are estimated from thermogravimetric experimental data

4. Case study results

For the case study, the mass composition of the fuel part of the waste (FPW) is the following: C: 0.657929, H: 0.091236, O: 0.248008, N: 0.00257, S: 0,000257. Taking into account the moisture and ashes, the waste formula is:

$$CH_{1.6525}O_{0.2830}N_{0.0033}S_{0.0001},\ 0.09636H_2O,\ 0.05625SiO_2$$

The FPW inferior heating power is estimated to 27330 kJ/kg. The waste total flowrate is 6.25t/h. The characteristics of the air feeds for drying, combustion and decarbonation are respectively:

- total flowrates : 4435, 9790 and 1000 Nm^3/h
- temperatures, after preheating: 360, 600 and 600 °C

With these data, the temperature in the gaseifier chamber 2, where take place pyrolysis, combustion and gasification, is 750 °C. The repartition of the head space incoming molar flowrates are shown in figure 4. Most of gas, 64 mol%, is produced by combustion / gasification. The contribution of pyrolysis gas is 29 mol% and 7 mol% is coming from decarbonation.

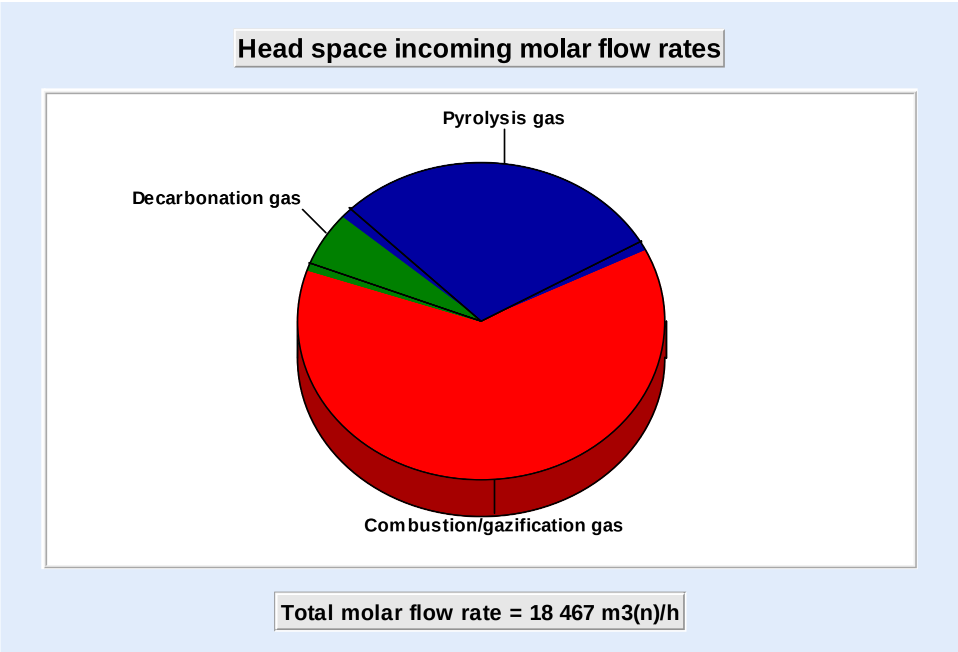

Figure 4: Head space incoming molar flowrates

Table 1 shows the results obtained by simulation. The IHP of the syngas is 5157 kJ/Nm^3 .

From sensitivity analysis, two model parameters appear essential in order to have a good representation of the gasifier operation: the waste IHP and the waste carbon conversion rate into pyrolysis gas. The first fixed the thermal power available while the second specifies the repartition between the exothermicity and endothermicity potential. Their balancing, to ensure the gasifier adiabaticity, determines the operating temperature of the gasifier.

5. Conclusion

In this paper, we have proposed an original approach for the modeling of an industrial gasifier. The gasifier model is built up in three steps: decomposition in elementary components associated to gasifier structure and physicochemical phenomena and definition of subsystems; build up of the ProSimPlus® simulation diagrams of the subsystems from standard modules; aggregation of the sub diagrams to obtain the whole gasifier model. The first results obtained are physically correct, allowing the use of the model as decision-making tool for process design and operation. Notably a sensitivity analysis of the gasifier with respect to its operating parameters is currently underway. The final goal is to improve the efficiency of the waste conversion into electricity. Additional experimental tests related to waste characterization and their pyrolysis are scheduled for definitively validating the proposed model.

	Wet air out of drying section	**Syngas**	**Ashes**
Total Flowrate			
Mass (kg/h)	6173	18743	932
Mol (Nm^3/h)	5013	18467	389
Mass fractions			
Char (C)	0	0	0.03
O_2	0.2154	0	0
N_2	0.7094	0.5684	0
H_2O	0.0752	0.0123	0
H_2	0	0.0182	
CO	0	0.3288	0
CO_2	0	0.0512	0
CH_4	0	0.0158	0
C_7H_8	0	0.0014	0
$C_{10}H_8$	0	0.0019	0
H_2S	0	$3.55\ 10^{-5}$	0
SO_2	0	$6.67\ 10^{-5}$	0
NO	0	$7.17\ 10^{-4}$	0
NO_2	0	$1.10\ 10^{-3}$	0
Ashes	0	0	0.97

Table 1: Simulation results

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