Energy 93 (2015) 864–873

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Assessment of municipal solid wastes gasification in a semi-industrial gasifier using syngas quality indices

Nuno Dinis Couto [a], Valter Bruno Silva [a], Eliseu Monteiro [b], Abel Rouboa [a, c, *]

[a] INEGI-FEUP, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
[b] INEGI-FEUP, Polytechnic Institute of Portalegre, Portalegre, Portugal
[c] MEAM Department, University of Pennsylvania, Philadelphia, PA 19020, USA

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form
4 September 2015
Accepted 14 September 2015
Available online 22 October 2015

Keywords:
Syngas quality indices
Gasification
Municipal solid wastes
CFD
Semi-industrial gasifier

ABSTRACT

In this work a comprehensive two-dimensional CFD model was used in order to assess the potential of syngas produced from gasification of Portuguese MSW (municipal solid waste) by using a semi-industrial gasification plant. An Eulerian–Eulerian approach within the computational fluid dynamics Fluent framework was used to describe the transport of mass, momentum and energy for both solid and gas phases. Pyrolysis was also modeled. Numerical results were validated against experimental ones. Results were in good agreement with each other. Influence of temperature, MSW admission and equivalent ratio on products of gasification and their concentrations were studied. Considering operating conditions influence on the combustible gases, it was concluded that gasification temperature had the greatest influence on syngas heating value. After analyzing syngas composition and other gasification products the best use for a particular produced syngas was investigated. For the MSW used in this work one of the most promising uses for the obtained syngas was for chemical fuel application.

1. Introduction

MSW (municipal solid waste) collection and disposal is a major urban environment issue in the world today. MSW to energy generates a renewable energy source and has attracted the attention of both national and local governments with various preferential policies.

There are emergent support schemes worldwide to promote power generation from renewable energy sources [1] because of the retreating conventional sources of energy, frequent energy security issues, and increasing public environmental awareness.

According to the concept of sustainable waste disposal, a successful treatment of MSW should be safe, effective, and environmentally friendly [2]. However, the current waste-disposal methods do not meet these goals. Landfills occupy large amounts of land and lead to serious environment problems [3]. Incineration technology was developed to reduce the total volume of waste and make use of the chemical energy of MSW for energy production. However, MSW incineration is a highly complex technology, which involves large investments and high operating costs. On top of that, these types of systems produce a wide variety of pollutants that can be harmful to human health. Meaning that it is necessary to find a new way to not only eliminate or control the toxic emissions from chemically complex MSW but also minimize investment and operating costs.

During gasification of MSW, the chemical energy content in the carbonaceous fractions of the waste is converted, under sub-stoichiometric conditions, to a gaseous product or syngas [4]. As a waste-to-energy technology, gasification offers remarkable opportunities for increasing overall plant efficiencies by utilization of the syngas in higher efficiency electricity-production system, such as gas turbines, reciprocating engines [5] and fuels cells [6]. The syngas specific composition depends upon the fuel source and the processing technique. The substantial variations in syngas composition and heating value are among the largest barriers toward their usage [7].

Therefore, measurements of the gas-species composition of the syngas produced from gasification of MSW under different operating condition of gas temperature and residence time showed that carbon monoxide, hydrogen, methane, ethane and acetylene are

* Corresponding author. Quinta de Prados, Apartado 1013, 5001-801 Vila Real, Portugal. Tel.: +351 259350317; fax: +351 259 350 356.
E-mail addresses: nunodiniscouto@hotmail.com (N.D. Couto), vbrsilva@utad.pt (V.B. Silva), ELMMonteiro@portugalmail.pt (E. Monteiro), rouboa@seas.upenn.edu (A. Rouboa).

http://dx.doi.org/10.1016/j.energy.2015.09.064
0360-5442/

the main gas-phase species present in the syngas under gas temperature conditions in the range between 750 and 900 °C, typical in commercial gasification technologies [8].

Measurements of tars composition in the syngas produced from MSW [8] showed that benzene and benzene derivatives are the main tar components under typical gasification conditions, which are also the main tar components obtained from biomass gasification [9]. Since tar formation can cause severe problems in the gasification process it is necessary to maximize its removal. Devi et al. [10] provided an overview of the primary methods used for tar removal. According to the authors all tars should be prevented or eliminated in the gasifier by manipulating factors like operating conditions, addition of active bed materials and possible reactor design modifications.

The production of syngas from the gasification of MSW is a recent subject and, hence, shortly reported in the scientific literature [6,11,12].

Syngas application greatly depends not only on MSW composition but also on operating conditions. In fact, optimization of the operating conditions can improve syngas characteristics from a certain application like, fuels and chemical synthesis applications or for hydrogen and fuel gas applications, among others [13].

The traditional approach indispensable to establish commercial plant technology is based on full experimental investigations, progressing from a laboratory scale test unit to a pilot scale plant, before building a full-scale commercial demonstration plant. Results from semi-industrial plants present far more importance for commercial ones due to the fact that results are much more close to reality than laboratory ones. For process optimization, an extensive investigation of the plant behavior depending on various operating parameters is required for each scale up step. To support this optimization procedure, mathematical models are helpful to reduce the temporal and financial efforts.

Numerical models can also be very useful for predicting the gasification process including syngas composition and in particular syngas quality indices. There are several papers in the literature trying to successfully describe the gasification process using different substrates [14–16].

The aim of this paper is to assess the syngas production from MSW gasification using a numerical method. For this propose, a two-dimensional mathematical model developed and validated in an earlier work [17] based on an Eulerian–Eulerian approach and capable to simulate fluidized-bed MSW gasification within Fluent is used. The model was validated using data collected from the literature and then expended to predict the process on a semi-industrial gasifier. Applications of syngas obtained from MSW gasification in the Lipor (North of Portugal) is taken as a case study. An assessment of the potential of gasification can only be made after modeling the products of gasification and their concentrations at different operating conditions. In this study, we attempted to do so for MSW by predicting the relative concentrations of process products using the computer package Fluent. Using a wide set of experiments the obtained concentrations, as well as other gasification products, the best use for the syngas produced will be investigated.

2. Materials and methods

The simulations were performed in an up-flow atmospheric fluidized bed gasifier. This fluidized bed reactor is a tubular reactor of 0.5 m in diameter and 4.15 m of height, internally coated with ceramic refractory materials; MSW enters the reactor at the height of 0.5 m, from its base, and preheated air at 600 K enters the reactor coming from the base through a set of diffusers, ensuring an adjustable flow. The schematics of the fluidized reactor as well as in depth analysis on the gasification plant can be seen in [15,17].

2.1. Municipal solid waste characterization

MSW increases significantly in industrialized and developing countries, raising questions about sustainable municipal solid waste management. This results from the collection of waste in large urban areas, and comprises materials such as household waste, plastic, paper, glass, metals, and garden waste [18]. The composition of municipal solid waste depends on both the season and geographic location. The heterogeneous nature of the wastes affects the physical properties in terms of size, elemental composition, moisture content, heating value, ash content, volatile content and other contaminants. Therefore, the wastes are pre-treated accordingly to the Portuguese management system described by Teixeira et al. [3].

Lipor is the entity responsible for the management, treatment and recovery of MSW in the Oporto metropolitan area. This includes eight municipalities in the Oporto metropolitan area and a production of about 500 Ktons/year of MSW [19]. During the year 2012 a sampling campaign was carried out. A criteria analysis of the waste collected was held, and the physical characterization by categories is shown in Table 1.

From the pre-treatment results a RDF which contains cellulosic materials and plastics due to putrefied wastes, paper, wood wastes, and plastic residues. The remaining MSW components follow another route for valorization or elimination. Plastic residues are mainly composed of polyethylene, polystyrene, and poly-vinyl chloride [20] and the cellulosic materials are composed of cellulose, hemicelluloses, and lignin [21].

Given that the ultimate analyses does not distinguish the cellulosic materials, it was postulated that their composition was similar to the one found in Onel et al. [16], where the cellulosic material comprises cellulose, hemicellulose and lignin. Regarding the plastics group, report shows the relative quantities of each monomer in the MSW. Therefore, it was possible to take into account different monomers for the plastics group as shown in Table 2.

In order to model the gasification process it is necessary to formulate the MSW mixture in Fluent. Waste characterization shown in Table 2 can be used to this end. Ultimate analysis of the mixture is used to found fractions of carbon (C), hydrogen (H) and oxygen (O).

3. Mathematical model

The two-dimensional mathematical model developed by Silva and Couto [15,22] for biomass gasification and extended by Couto

Table 1
Physical characterization of the MSW [19].

Category	Winter (% weight)	Summer (% weight)
Putrefied residues	44.34%	44.29%
Paper	4.74%	5.30%
Cardboard	2.61%	4.21%
Composites	4.68%	5.40%
Textiles	5.73%	6.76%
Sanitary textiles	11.20%	6.28%
Plastics	10.98%	13.44%
Combustive non specified	0.09%	0.97%
Glass	4.29%	4.80%
Metals	2.15%	1.97%
Non-combustive non specified	0.41%	0.46%
Hazardous residues	0.06%	0.01%
Fine elements	8.72%	8.10%