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Hydrogen-rich gas from gasification of Portuguese municipal solid wastes

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ABSTRACT

Gasification has been identified as a promising method of municipal solid waste (MSW) conversion to energy due to its pollution minimization effects and high overall efficiency. Recent studies have been carried out to produce hydrogen through MSW gasification with promising results. Despite this, it is still necessary to develop mathematical models able to assist the advance of this technology and to make way for large-scale commercialization.

A previously developed and validated numerical model was used to predict and analyze the viability of hydrogen-rich gas generation from MSW gasification in a semi-industrial fluidized bed gasifier. Influence of equivalence ratio, carbon-dioxide-to-MSW ratio, steam-to-MSW ratio, reactor temperature and catalyst used was investigated. The content of hydrogen in the generated gas increased up to 40% with the presence of NiO/MD catalysts, while reducing the tar content and increasing the gas yield. Finally, to assess the capabilities of the Portuguese wastes results were compared with previously studied Portuguese biomass substrates.

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Introduction

The depletion of fossil fuels reserves, geopolitical fears associated with fossil fuel scarcity, and issues of environmental pollution and climate change as well as the need to ensure independence of energy supply make the low-carbon economy with a crucial hydrogen vector inevitable in the coming years.

Hydrogen as a clean energy carrier is expected to satisfy a considerable portion of the world's future energy needs [1,2]. It can be used in internal combustion engines as well as in fuel cells with less pollution on the environment, since the combustion with oxygen produces water as its only by-product [3]. Moreover, it has the highest energy content in comparison to other common fuels.

A rising concern is that fossil fuels make up by far the largest contemporary source of hydrogen (approximately 97% [4]). Taking into account fossil fuels scarcity concerns along with high carbon footprint [5] research on renewable alternative source of hydrogen is needed [6]. Biagini et al. [7] conducted an experimental study to evaluate the performance of the different thermo-chemical technologies (i.e. combustion,

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Nomenclature

A, B	calibration constants
A_i	pre-exponential factor
$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$	Constants
C_p	Specific heat capacity
D_0	Diffusion rate coefficient
E_i	activation energy
G_k	Generation of turbulence kinetic energy due to the mean velocity gradients
G_b	Generation of turbulence kinetic energy due to buoyancy
h_q	Specific enthalpy of phase
h_{pq}	Heat transfer coefficient between the fluid phase and the solid phase
k	Thermal conductivity
Nu	Nusselt Number
$\dot{m}$	Biomass flow entering into the gasifier
M	Total mole flow of carbon in the syngas components
M_i	Molecular weight of each the species
M_c	Molecular weight
$M_{w,i}$	Molecular weight of i component
p	Gas pressure
Pr	Prandtl Number
p_s	Particle phase pressure due to particle collisions
$\vec{Q}_{pq}$	Heat transfer between pth and qth phases
$\vec{q}_q$	Heat flux
q^{th}	Specific enthalpy
R	Universal gas constant
$\mathbf{R_i}$	Net generation rate of specie i due to homogeneous reaction
Re	Reynolds Number
R_c	Reaction rate
$\mathbf{S_i}$	Source term of the species i production from the solid heterogeneous reaction
S_k	User-defined source terms
S_q	Source term due to chemical reactions
S_ε	User-defined source terms
T	Temperature
t_s	Particle phase stress tensor
U	Mean velocity
v	Instantaneous velocity
$\mathbf{X_C}$	Carbon fraction in the biomass (obtained from the ultimate analysis)
Y	Mass Fraction
Y_M	Contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate

Other symbols

α	Volume fraction
β	gas–solid interphase drag coefficient
γ_c	Stoichiometric coefficient
γ_{Θ_2}	Collisional dissipation of energy
ε	dissipation rate
ρ	Density
φ_{ls}	Energy exchange between gas and solid phases
k_{Θ_2}	Diffusion coefficient
$k_{\Theta_2}\nabla(\Theta_s)$	Diffusion energy
$(-p_s\bar{I} + \bar{\tau}_s) : \nabla(\vec{v}_s)$	Generation of energy by the solid stress tensor.
τ	Tensor stress
μ	Viscosity

Subscripts

g	gas phase
s	solid phase
i	component

gasification, electrolysis and syngas separation) for hydrogen production from biomass. They reported that the hydrogen production was maximized for the gasification/separation process followed by gasification/electrolysis and the least being combustion/electrolysis. Therefore, among the aforementioned technology options, gasification of biomass is identified as the most efficient and economical route for hydrogen production.

Among biomass sources, municipal solid wastes (MSW) are the largest volume of residues produced worldwide; at the same time, the citizens' demands for an environmentally sound management of MSW have significantly increased during the last decades [8].

The Integrated Solid Waste Management includes several solutions to achieve lower environmental and social impacts. These solutions combine different alternatives such as waste generation reduction, material recovery, recycling, and energy recovery and as least desirable option, landfills. This practice is incorporated to any modern strategy involving MSW management [9]. The disposal of MSW has become a critical and costly problem. The traditional landfilling method requires large amounts of land and contaminates air, water and soil [10]. Furthermore, incineration has drawbacks as well particularly harmful emissions of acidic gases (SOx, HCl, NOx, etc.), dioxin and leachable toxic heavy metals [9].

The application of MSW gasification has enormous prospects in energy security, mitigation of climate change and sustainable settlement development. A number of thermochemical processes can convert the carbonaceous materials of biomass to a combustible syngas where gasification plays lead role [9].

Gasification is a high-temperature partial oxidation process in which a solid carbonaceous feedstock such as MSW is converted into a gaseous mixture (H_2, CO, CO_2, CH_4, light hydrocarbons, tar, char, ash and minor contaminates) using an oxidizing agent [11]. Several studies have been performed to increase the hydrogen production yield from biomass gasification [12]. Due to the large range of investigations, experimental [13–15], mathematical and computational [16–19] approaches have been applied to conduct these studies. Regarding MSW gasification, available studies are still very scarce especially considering semi-industrial or industrial conditions.

He et al. [13,14] studied the influence of steam to MSW ratios and weight hourly space velocity [13] and the influence of catalyst and temperature on yield and product composition

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