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Potential of Hydrogen Production from Pepper Waste Gasification

Zuhal AKYÜREK[a], Ali Özhan AKYÜZ[b], Afşin GÜNGÖR[c,d*]

[a]Faculty of Engineering and Architecture, Mehmet Akif Ersoy University, Istiklal Campus, 15030, Burdur, Turkey
[b]Bucak Emin Gulmez Technical Sciences Vocational Higher School, Burdur Mehmet Akif Ersoy University, Burdur, Turkey
[c]Faculty of Technology, Mehmet Akif Ersoy University, 15300, Bucak Campus, Bucak, Burdur, Turkey
[d]Faculty of Engineering, Akdeniz University, 07058, Antalya, Turkey, afsingungor@hotmail.com

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Abstract: Gasification is a promising clean energy technology for hydrogen production and sustainable waste management. Biomass residues have great potential to produce renewable hydrogen. In this study, the potential of production of hydrogen from pepper residues was determined via a modeling study of air/steam gasification system. The input carbon of the feedstock was assumed to be fully gasified in the numerical model calculations performed for the downdraft gasifier system. Air to fuel ratio (A/F) and steam to fuel (S/F) ratio are taken as 0.05 because of the high oxygen content in pepper waste. The temperature of the gasifier is 877 °C for the developed mathematical model. The modeling study results revealed high hydrogen content in the producer gas derived from pepper waste gasification which has obtained as 49.08 %.

Keywords: Gasification, pepper residue, hydrogen production, renewable energy, waste management.

Biber Atıklarının Gazlaştırılmasının Hidrojen Üretim Potansiyeli

Öz: Gazlaştırma, hidrojen üretimi ve sürdürülebilir atık yönetimi için umut verici bir temiz enerji teknolojisidir. Biyokütle atıkları yenilenebilir hidrojen üretme konusunda büyük potansiyele sahiptir. Bu çalışmada, biber atıklarının hidrojen üretim potansiyelini hava-buhar gazlaştırma teknolojisi ile incelemek için bir modelleme çalışması yapılmıştır. Aşağı çekiş gazlaştırma sistemi için geliştirilen sayısal model, yakıt karışımındaki tüm karbonun gazlaştırıldığını varsayar. Biber artığındaki yüksek O2 içeriğinden dolayı hava/yakıt ve buhar/yakıt oranı 0,05 olarak alınmıştır. Geliştirilen model için gazlaştırma sıcaklığı 877 °C 'dir. Modelleme sonucuna göre, biber atıklarının gazlaştırılması ile üretilen gazdaki hidrojen içeriği % 49,08 olarak elde edilmiştir.

Anahtar kelimeler: Gazlaştırma, biber atığı, hidrojen üretimi, yenilenebilir enerji, atık yönetimi.

[1]. Introduction

The energy demand has been increasing due to rapid growth in population, industrialization and improvement of living standards of the society. Energy supply, economic development, sustainable environment are the main drivers of national energy policies in any country of the world today. Greenhouse emissions from fossil fuels have caused a long term and irreversible damage to the environment leading to global warming and climate change [1]. To reduce the negative impacts of fossil energy, integration of renewable energy systems has been increasing in both number and capacity.

Biomass is one of the promising alternatives to meet energy demand and reducing CO2 emissions [2-7]. Biomass can be derived from agricultural crops, forestry, agro-industrial and domestic wastes (municipal solid waste). Unlike the other renewables, biomass energy can be readily stored and

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Bu makaleye atıf yapmak için
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transformed into electricity and heat. Utilization of greenhouse residues have several advantages such as recovering energy from waste materials, using local renewable energy source, decreasing the volume of solid waste dumped in landfills and avoiding methane emissions from the landfills. Utilization of organic wastes gain importance in terms of sustainable waste management.

Among the bio-waste to energy technologies, gasification is an attractive option for a wide range of applications. Gasification is an environmentally friendly way of using biomass for power generating purposes [8-11]. It is an effective technology for producing hydrogen to be used in fuel cells and internal combustion engines. Biomass has the potential to become a significant source of renewable hydrogen [12,13]. During gasification biomass feedstock turns into syngas gas mixture by the partial oxidation reactions taking place at high temperatures (800-1000 °C) [14]. Gasification process can be performed by air, oxygen and/or steam gasifying agents. Product of the gasification system is termed as producer gas which is composed of different constituents such as hydrogen, carbon monoxide, carbon dioxide, methane and nitrogen [15].

Mathematical modeling of gasification of biomass can help to improve design and operation of the gasifier, solve associated operational problems and promote the application of gasification technology [16-18]. Mathematical modeling includes several advantages like producing high number of data points from lower number of experimental data. The advantage of mathematical modeling is highly acknowledged by researchers worldwide and it is used as tools for investigation and optimization of the process of gasification [19].

In 1940s greenhouse agricultural production started in Turkey. They mostly built around Antalya province due to Mediterranean climate which is very convenient for greenhouse cultivation. About 93 % of the glass greenhouses and 52 % of the plastic greenhouses in Turkey are located in Antalya province (Turkish Statistical Institute, TUIK, 2018) [20]. In this study, pepper residue has taken as the biomass source for gasification. Air/steam are used as the gasifying agent. Model simulations of gasification process were performed with 100% efficiency for carbon conversion. This study has evaluated the gasification and hydrogen production potential of pepper waste.

2. Methods and Modeling

The optimization of synthesis gas composition for power generation is a hardening issue. Clear assessment of the gasification process is required to predict gasification process performance through modeling. Model development is very practical for the process analysis and reactor designing. In this regard, in this study, assessment of performance of pepper residue gasification is simulated by a previously developed and validated model [17]. The schematic description of the system is shown in Figure 1. The model under consideration assumes that all the reactions taking place in the gasifier are in thermodynamic equilibrium with each other. For preliminary comparison and first estimate, thermodynamic equilibrium model (TEM) is a simple and practical tool. The impact of feedstock and parameters of the process are studied conveniently in TEM irrespective of the gasifier design and produces a reasonable prediction for the maximum achievable product for a designer. The gasification reactions used for the model are presented in Table 1. The equilibrium constants of Boudouard, Water Gas Shift (WGS) and Methanation Reaction are given in Table 2 [21, 22]. The model assumes isothermal operation and occurrence of chemical equilibrium. A combined relaxation Newton–Raphson method is used in the model, by means of Visual Basic.Net.

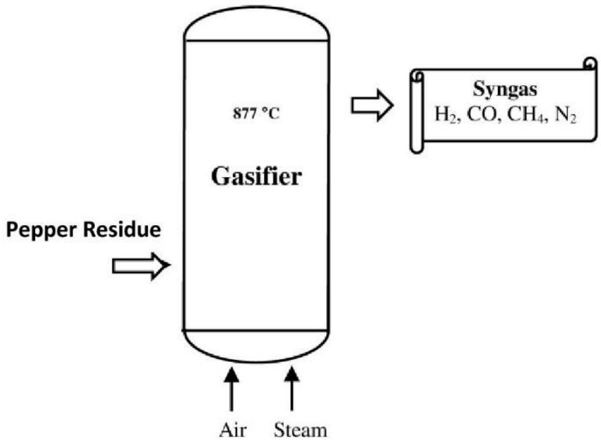

Figure 1. Schematic description of the downdraft gasification system.

Feeding rate of biomass, biomass characteristic properties, temperature and pressure of gasification and pressure, air/fuel ratio, and steam/fuel ratio are taken as the input parameters for the model.

Table 1. Chemical reactions occurred in the gasifier [21,22]

No	Reactions	Equals
1	Oxidation I	$C + O_2 = CO_2 \quad (-394.5\,kj/mol)$
2	Oxidation II	$C + \frac{1}{2}O_2 = CO \quad (-111.5\,kj/mol)$
3	Steam Gasification	$C+H_2O=CO+H_2 \quad (+131.4\,kj/mol)$
4	Boudouard Reaction	$C+CO_2=2CO \quad (+172.6\,kj/mol)$
5	Methanation Reaction	$C+2H_2=CH_4 \quad (-74.9\,kj/mol)$
6	Steam Reforming Reaction	$CH_4+H_2O=CO+3H_2 \quad (+206.2\,kj/mol)$
7	Water Gas Shift Reaction	$CO+H_2O=CO_2+H_2 \quad (-41.2\,kj/mol)$

The producer gas composition, H_2/CO and higher heating value are calculated by the simulation model for the air/fuel ratio and steam/fuel ratio under certain operating conditions. The ultimate analysis of pepper residue is presented in Table 3.

Table 2. Equilibrium constants [21-23]

Temperature (K)	K_{pw}reaction(3)	K_{pb}reaction(4)	K_{pm} reaction(5)	K_{ps} reaction (7)
400	$7.7x10^{-11}$	$5.2x10^{-14}$	$2.99x10^{5}$	4050.00
600	$5.1x10^{-5}$	$1.9x10^{-6}$	$9.24x10^{1}$	27.00
800	$4.4x10^{-2}$	$1.1x10^{-2}$	$1.34x10^{0}$	4.04
1000	$2.62x10^{0}$	$1.90x10^{0}$	$9.6x10^{-2}$	1.38
1500	$6.08x10^{2}$	$1.62x10^{3}$	$2.5x10^{-3}$	0.37

Table 3. Elemental analysis of pepper residue

C (%)	H (%)	O (%)	N (%)	Moisture (%)
39.27	4.17	35.01	3.28	10.00

3. Results and Discussion

The modeling results of pepper residue gasification is demonstrated in Figure 2. As can be seen from the figure hydrogen content of the producer gas is 49.08 %. High amount of hydrogen production in biomass gasification is attributed to the high oxygen content of feedstock. The gasification efficiency is calculated as 83.45 %. Higher heating value (HHV) of the product gas is calculated as 17.67 MJ/kg. The results are in good agreement with the gasification studies carried out with similar agricultural residues in literature [11, 13, 15].

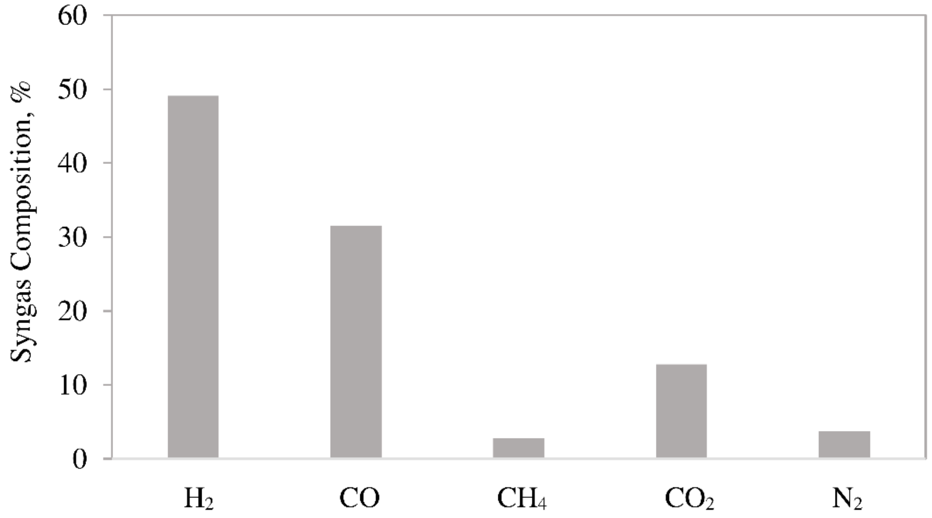

Figure 2. Composition of the producer gas at A/F = 0.05, S/F = 0.05, P = 1 atm, T = 1150 K

4. Conclusion

Hydrogen is considered to be one of the most significant energy carriers for future. Biomass gasification is an effective process for hydrogen production and for promoting sustainable waste management solutions. In the current study, the gasification performance and efficiency of pepper residue is evaluated by the developed mathematical model from the hydrogen production point of view. This study proved that pepper residue can be a promising hydrogen source. The high oxygen content of pepper residue is an important driver in view of production of hydrogen.

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