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Original Research Article

Hydrogen production from groundnut shell via circulating fluidized bed technology

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ABSTRACT

In this study, hydrogen production performances of groundnut shells in a circulating fluidized bed gasifier is evaluated by employing a previously developed and validated model. Basically, we simulate a circulating fluidized bed gasification system that is connected to a water-gas shift reactor, for hydrogen purification with the gasifier temperature of 1150 K. We find that the amount of hydrogen gas produced from circulating fluidized bed gasification of groundnut shells increases from 49.25 kmol to 68.83 kmol (per 1000 kg of raw groundnut shells) when the gasifier is integrated with water-gas shift reactor. We observe that it is possible to obtain a high yield of hydrogen gas from the gasification of groundnut shells. Therefore, we conclude that the groundnut shell is a remarkable feedstock for bioenergy.

Keywords: Circulating fluidized bed gasification; Groundnut shell; Sustainable energy technology; Hydrogen purification

1. Introduction

The depletion of fossil fuel resources and climate changes as a consequence of increasing environmental pollution have increased the attention on environmentally friendly energy resources and sustainable conversion technologies. The International Energy Agency's World Energy Outlook in 2016 reported that the share of biomass accounts for 9.7% of the global energy mix in the world. This ratio is far behind the three main energy sources, namely, 31.7% oil, 28.1% coal and 21.6% natural gas in the global energy supply [1]. Renewable energy sources are evaluated in terms of zero-emission, infiniteness, and easy applicability aspects. Biomass is of great potential worldwide with respect to sustainable energy supply, given its high availability, renewable status and the possibility of productively utilizing waste materials [2-4]. The term "biomass" refers to carbonaceous materials derived from agricultural crops, forestry, agro-industrial, and domestic wastes. Fuels derived from biomass resources reduce net CO_2 emissions during their processing owing to their inherent carbon-neutral nature. Hence, plentiful biomass resources are good candidates for the siting of facilities to produce green energy. Nowadays, intensive research has been conducting on the energy production of biomass as an alternative to fossil fuels. A variety of methods such as biomass gasification, biomass pyrolysis, biomass liquefaction etc. are used in hydrogen production [5-7]. Note that hydrogen is a significant renewable product gas and biomass is a rich source of hydrogen [8].

Gasification is one of the major biomass utilization technologies to produce high-quality gas. It converts biomass waste into a clean and usable form of energy. It is partly a process of thermal oxidation resulting in the production of gaseous products with high flammability properties [9]. The process of gasification results in a synthesis gas comprising various combustible gases such as hydrogen, oxygen, and methane [10]. Because hydrogen is emerging as a clean and sustainable fuel that can be used to control carbon emission, it has gained increasing interest in the industry [11-15]. Hydrogen has approximately three times higher heating value than that of natural gas [16]. However, hydrogen is not readily available in nature. About all the hydrogen production is derived from fossil fuel hydrocarbon reforming, particularly natural gas. Therefore, biomass is accepted an advantageous and sustainable option to produce hydrogen gas through gasification technologies [17, 18].

Fluidized bed technology is widely used in gasification because of its various advantages including high heat transfer, uniform and controllable temperature, favorable gas-solid contact and fuel flexibility [19-20]. Fluidized bed gasification (FBG) of biomass by using air–steam mixture as the gasifying agent is an economically available potential solution to produce syngas with high hydrogen content. The partial combustion of biomass in the gasifier can be converted to an automatic thermal process by providing the necessary energy for the process [21]. Several experimental studies have reported that feeding a stream of steam with airflow during FBG of biomass results in improvements in the gas quality [22-25].

Groundnut shell is one of the waste biomass materials having great potential for commercial use [26]. Worldwide production of groundnut was about 42.8 million tons in 2016. China is the leading producer of groundnut in the world. In 2016, it is recorded their production reached 16.7 million tons. This value corresponded 39% of the world's total production. India, Nigeria, and USA are other important producer countries with 6.9 million tons (16%), 3.0 million tons (7%) and 2.6 million tons (6%) of groundnut production, respectively [27].

Mathematical modeling can be performed for different purposes, from the initial design of an industrial process to the final design of a specific process [28-31]. Simulation of gasification processes help to observe a comprehensive understanding of the chemical and physical mechanisms of the gasification systems, therefore leads to the design of new systems in the best possible way which saves money and time. Numerous studies have been performed on simulation and modeling of FBG systems [32-34]. Gasification performance was investigated in different particle size of biomass wastes, thermal conditions and with various catalysts [35, 36]. However, limited work has been conducted on the thermal transformation of groundnut shells. The studies have mostly focused on combustion performance of groundnut shells while a few studies have been carried out evaluating groundnut shell as an energy source through gasification and hydrogen production [26, 37, 38].

As a consequence of environmental pollution, global warming and the depletion of fossil sources, mankind should use renewable and nature friendly energy sources. Without wasting time, the use of biomass resources has to become an appropriate alternative for renewable energy production. Its renewable nature makes biomass a promising potential source for sustainable hydrogen production. With this motivation, in this study, we employ a previously developed circulating FBG model [36], and we investigate the gasification performance and hydrogen production potential of the groundnut shells. We utilize air and steam in the gasification model. Then, we include a water-gas shift (WGS) reactor as the gasification agent for the hydrogen purification to the model. We perform the simulation in the gasification process with the optimal rates that are accepted to be 100% for carbon conversion efficiency.

2. Simulation and Validation

In this article, we employ a previously developed [36] and validated [39] two-dimensional numerical model to evaluate the performance of groundnut shell gasification and we examine the hydrodynamic efficiency of circulating fluidized bed (CFB) biomass gasifier. We demonstrate the flowchart of the model in Fig. 1. We assume that all of the reactions in biomass gasifiers are thermodynamically balanced with each other. In order to avoid unnecessary repetition, we do not give these reactions in this article, but one can find them in Table 1 [33]. Furthermore, we assume that the process of gasification is a single reaction in this model. We use the elemental balances and the equilibrium ratio between the reactions to evaluate the composition of the produced gas. Note that, we assume that the gasifier works isothermally and therefore, the chemical equilibrium is provided. In the model, we employ a combined relaxation Newton-Raphson method with the help of Visual Basic Net.

Table 1. The results of the FBG model for 1000 kg of groundnut shell usage

Syngas	Gasification		WGS	
	Amount (wt. %)	kmol	Amount (wt. %)	kmol
H_2	49.25	49.25	60.18	68.83
CO	44.40	42.40	20.11	23.00
CH_4	0	0	0	0
CO_2	0.039	0.04	17.00	19.44
H_2O	0.122	0.12	0	0
N_2	3.340	3.34	2.72	3.10

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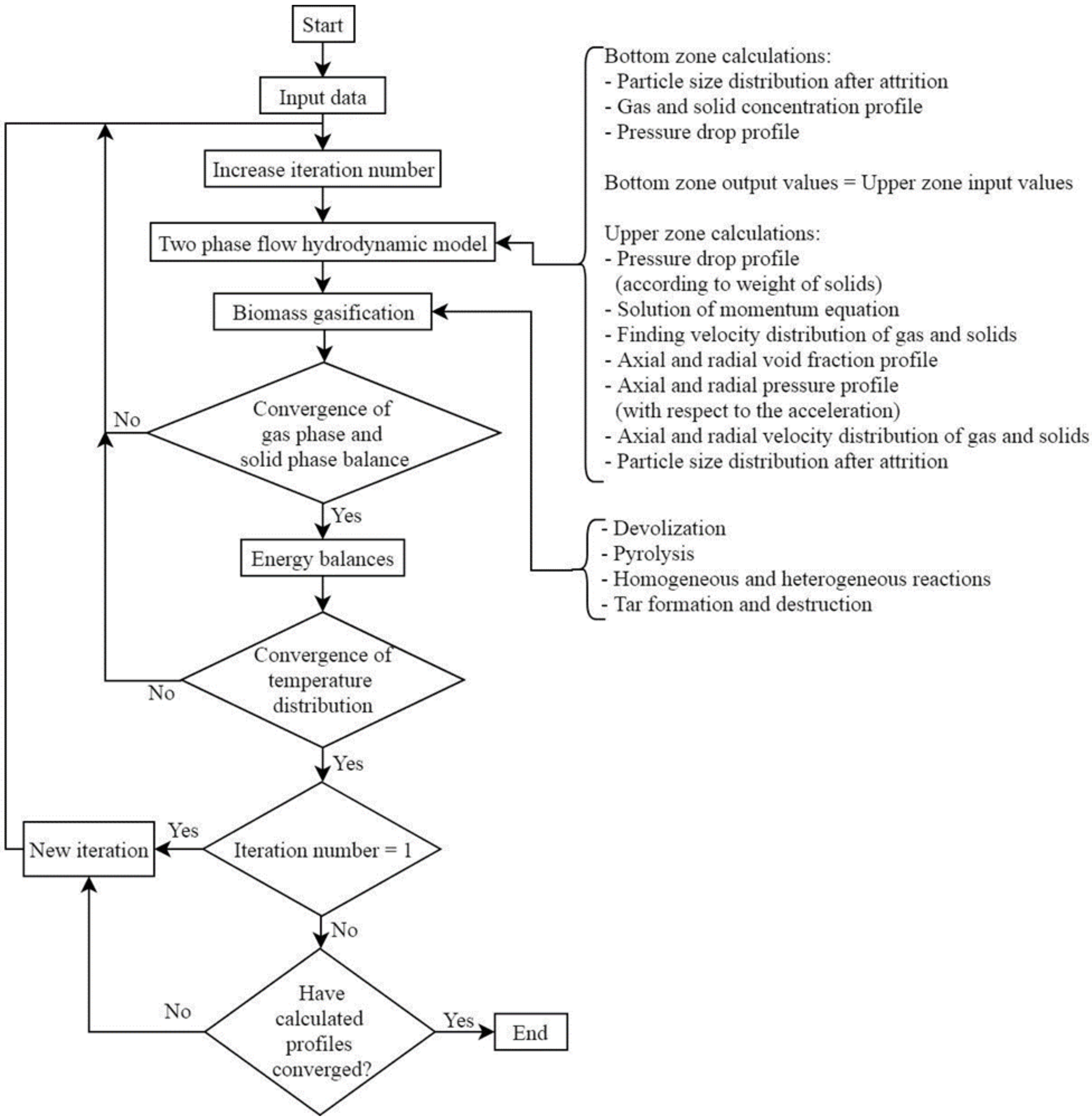

Fig. 1. Flowchart of the numerical model [36]

According to the flowchart, the model requires that syngas composition should be known at the beginning of the calculation. After entering the operation parameters such as steam-to-fuel ratios, air-to-fuel ratios and reactor temperatures, the model performs calculations for H_2/CO ratio. If the calculations converge to a solution, the program saves the results to a file and stops. As a final step, the model validates the desired H_2/CO ratio. If this ratio satisfies the criteria, the program computes the higher heating value (HHV) of the resulting syngas composition as well as hot and cold gas efficiencies of the system.

H_2, CO, H_2S, CH_4 and the sum of the heating values of the individual combustible constituents are used to calculate HHV of the synthesis gas. Numerous references can easily be found concerning in various temperatures of the enthalpies and the heating values of these gases [40]. In our study, H_2S and CH_4 possess very small amount, therefore, we neglect them and calculate the heating value without their effects. We take the range of the gasifier temperature in between 977–1153 K. Note that, the efficiency of gasification depends on temperature, for example at low temperature, the system is less effective and the tar content of the gas is excessive. The model results were also compared with the experimental results of Subbaiah *et al.* who have carried out CFB gasification experiments for groundnut shells under similar operational conditions.

3. Results and Discussion

Climate change concerns have triggered the interest in clean energy technologies that meet the environmental and political requirements. Gasification technology provides conversion of biomass into gaseous secondary energy carriers via partial oxidation at high temperature. There are many power plants reported in literature having circulating FBGs connected to large conventional boilers. In this work, we have studied the production of hydrogen gas from groundnut shells in a circulating FBG using a previously developed and validated numerical model. The model results for syngas composition were also compared with the experimental results of CFB gasification of groundnut shells under similar operational conditions.

The water gas shift is a significant reaction widely employed in industry for upgrading the syngas, where hydrogen production rate is increased, and carbon monoxide concentration is reduced by conversion of carbon monoxide to carbon dioxide. We have employed a WGS reactor for the purification of H_2. We assumed that the produced syngas from the gasification process penetrates the WGS reactor with the steam feed in order to purify H_2. In Fig. 2, we illustrate the schematic representation of the gasification process.

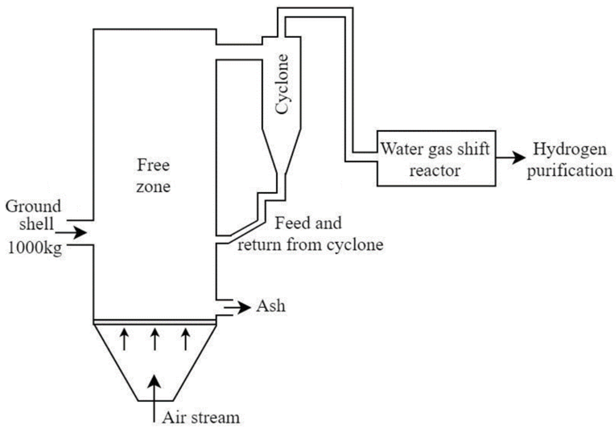

Fig. 2. Schematic representation of gasification process

In correspondence with general biomass characteristics, groundnut shells have high C and O contents and low H2 content. In [41], Kirubakaran *et al.* announce that a groundnut shell is composed of 48.3% Carbon, 39.4% Oxygen, 5.7% Hydrogen, 0.8% Nitrogen.

We executed the FBG model and tabulated the results for 1000 kg of groundnut in Table 1. We observe that H_2 has the highest amount (49.25%) in the syngas composition followed by CO (44.40%). Comparison of the model results with previous experimental data (Subbaiah *et al.)* were in good agreement with the experimental results for groundnut shells (H_2; 52.02%; CO; 48.99%) [42]. High CO amount is an undesirable condition due to its adverse effect on both carbon footp rint and hydrogen production. After the gasification reactor, syngas enters the WGS as a second reactor in order to reduce the CO ratio and increase H_2 production. The results of the FBG model integrated with the WGS reactor reveal an increase in H_2 amount from 49.25% to 60.18%. The amount of CO decreases from 44.40% to 20.11%, while the amount of CO_2 increases to 17.00% due to the integration of the WGS reaction. As a result, the developed mathematical modeling result is obtained by purifying 68.83 kmol H_2 gas from 1000 kg of groundnut shell. The gasification efficiency and HHV are calculated as 80.29% and 26.18 MJ/kg, respectively.

4. Conclusion

Hydrogen gas is thought to be one of the clean, and hence, a favorable energy source in the future. Recently, an increasing number of investigations on various hydrogen purification methods are being investigated. One of them is the biomass gasification, which is a very effective method. In this article, a numerical model of circulating FBG system is employed to evaluate the hydrogen purification production performance from the groundnut shells. This investigation shows that the O_2 content of groundnut shell residues is a significant factor in syngas production, mainly in hydrogen gas production. 1000 kg of gasified groundnut shells resulted in 68.83 kmol H_2 gas production with H_2 purification. The results reveal the importance of circulating fluidized bed gasification of groundnut shells in terms of H_2 production. With the development of hydrogen purification technology, biomass will play an important role in the development of the hydrogen economy and a sustainable environment.

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