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Journal of Chemical Engineering & Process Technology

Research Article

Optimization of the Physicochemical Parameters of Selected Crop Residues for Enhanced Biosynthetic Gas Yields

Wanasolo W[1]*; Okullo A[1]; Masa J[3]; Kalega I[2]; Gumula I[1] and Opedun J[1]

[1]*Department of Chemistry, Kyambogo University - Kampala, Uganda;* [2]*Uganda Industrial Research Institute, Nakawa, Uganda;* [3]*Ruhr-Universität Bochum; D-44780 Bochum, Germany*

ABSTRACT

In this study, the influence of physico-chemical parameters; average particle size, moisture, and cellulose content on the yield of biosynthetic gas from biomass pyrolysis was investigated. Response Surface Methodology and Box-Behnken design methods were used to analyze the experimental data. The results showed that at a given average particle size, the biosynthetic gas yield increased gradually with increase in cellulose content until at cellulose content of 35% when the yield starts to decrease with further increase in cellulose content. This implies that within experimental conditions, a cellulose content of 35% was ideal for obtaining maximum biosynthetic gas yield. The variations in average particle size affected biosynthetic gas yield in such a way that at low cellulose content below 30% and for a given average particle size, the biosynthetic gas yield was nearly constant. The same trend was observed at high cellulose content beyond 40%. However, between 30% and 40% cellulose content, the biosynthetic gas yield decreased with increase in average particle size until about 1.81 mm when the biosynthetic gas yield starts to increase with increase in average particle size. This implied that the minimum biosynthetic gas yield was obtained at 1.81 mm average particle size. It was concluded that for better biosynthetic gas yields, cellulose content of 35% would be preferred at average particle sizes other than 1.81 mm which yielded lowest biosynthetic gas.

Keywords: biosynthetic gas yield, crop residues, pyrolysis, optimization, physico-chemical parameter

INTRODUCTION

The use of fossil-based fuels as the principal energy source has continued to raise environmental issues and there are concerns of eventual depletion of the resource in the future (Ball & Wietschel, 2009; Bauen, 2006). Consequently, alternative sources of energy that are able to mitigate environmental issues and reduce on the consumption of fossil fuels are being promoted (Cherubini, 2010; Dincer, 1998, 2000). The most probable alternatives to crude oil reserves are bio-oils produced from pyrolysis of biomass as a raw material for fuel and chemical production and they offer an interesting option and driving force for the development of bio-fuel refinery complexes. In the bio-fuel refinery, almost all types of biomass feed stocks can be converted to different classes of biofuels and bio-chemicals through a combination of applied conversion technologies (Cherubini, 2010).

According to Lim, et al. (2012), biomass is one of the most promising alternative energy sources due to its natural carbon content and availability from multiple naturally occurring sources. Biomass can be thermo-chemically converted into solid and liquid fuels, as well as gases such as methane, carbon monoxide and

***Correspondence to**: Wanasolo W, Department of Chemistry, Kyambogo University - Kampala, Uganda, Tel: + 256783672226; E-mail: wanasolo@gmail.com

Received date: February 15, 2020; Accepted date: March 17, 2020; Published date: April 17, 2020

Citation: Wanasolo W, Okullo A, Masa J, Kalega I, Gumula I (2020) Optimization of the Physicochemical Parameters of Selected Crop Residues for Enhanced Biosynthetic Gas Yields. J Chem Eng Process Technol 11:401. doi: 10.35248/2157-7048.20.11.401

hydrogen by pyrolysis and gasification processes. The main reasons for use of biomass based fuels as alternatives to fossil-based energy sources are: environmental friendliness; renewability and generation of far less toxic emissions (Gokcol, et al., 2009). This implies that the wide availability of biomass capable of yielding petroleum-like products presents a sustainable and renewable alternative resource to fossil based fuels. Biomass materials such as agricultural wastes present a good opportunity for conversion to useful energy products. Some of these agricultural wastes that exist in large quantities in Uganda are groundnut shells, and coffee and rice husks. When pyrolyzed under suitable conditions, they can be converted into biofuels such as biochar and biosynthetic gas.

The biomass conversion technologies include: direct combustion, thermo-chemical processes, bio-chemical processes and agro-chemical processes. Thermo-chemical processes include gasification, pyrolysis, supercritical fluid extraction and direct liquefaction (Balat, 2009). The pyrolysis process converts biomass into liquid oils, biochar and non-condensable gases, acetic acid, acetone, higher hydrocarbon gases in minor quantities (Demirbaş, 2001). These energy rich products have many uses in transportation, thermal combustion and in the chemical industry for production of various chemical substances (Phuong, et al., 2014). Despite the importance of pyrolysis technologies, challenges still exist in ensuring efficient and effective pyrolysis process and selection of appropriate biomass with desirable properties and conditions suitable for high yields of quality products. Consequently, a study to determine the optimum conditions of process parameters for enhancement of biosynthetic gas yields was undertaken.

In Uganda, biomass materials such as groundnut shells, coffee and rice husks are in abundance and mostly gotten rid of through methods of open disposal and burning. This is because the country is highly agricultural and this has led to generation of huge amounts of agricultural wastes. The use of different agricultural biomass feed stocks in Uganda for fast pyrolytic conversion to useful products is still barely exploited. There are different crop varieties of groundnuts, coffee and rice grown in Uganda. However, the compositional quality parameters of this biomass in terms of cellulose, hemicellulose and lignin required for high pyrolysis product yields have not been established. The current research therefore sought to use groundnut shells, coffee and rice husks as feed stocks for pyrolysis to produce biosynthetic gas and to optimize the physico-chemical parameters that affect yields.

Furthermore, many studies have been conducted on the optimization of pyrolysis yields using the process conditions of temperature, pressure, heating rate and residence time, while others have focused on thermal decomposition properties and conversion pathways of the various biomass components (Nsaful, et al., 2015). No approach has been done on use of moisture, average particle size, and cellulose content to optimize biosynthetic gas yields. There are also other factors that affect the yield of bio-synthetic gas, namely; biomass type, average particle size of biomass, pyrolysis temperature, reactor efficiency, chemical composition of the biomass and initial moisture content. While some of these have been studied extensively for different biomass types, the effects of average particle size, moisture content, lignin and cellulose content for groundnut shells, coffee and rice husks from Uganda have not been reported.

MATERIALS AND METHODS

Parameter Levels

The variables that were investigated were average particle size; cellulose and moisture content. The parameters were varied according to the levels shown in **Table 1**.

Parameter	level	High	Mid	Low
Moisture content	Actual (% wt)	11.75	5.88	0
	Coded	1	0	-1
Average particle size	Actual (mm)	2.86	1.68	0.36
	Coded	1	0	-1
Cellulose content	Actual (% wt)	40.45	28.28	20.81
	Coded	1	0	-1

Table 1: Parameter levels.

Response Surface Method (RSM)-Box Behnken design was chosen so as to determine the ideal process settings and to achieve optimal performance for the selected design parameters. Box Behnken design was chosen because it created designs with desirable statistical properties, and generated a fraction of experimental runs required for its alternative 3-level factorial design. Within the goal of optimizing the process, Box-Behnken initial designs were used to fit levels of the selected parameters as high, mid and low, and coded as + 1, 0, and - 1, respectively. The quadratic model was found to be appropriate and satisfactory for the initial design. A total of 17 experimental runs were generated.

Pyrolysis

Each of the experimental runs were conducted by feeding 4 g of the conditioned sample into the tubular furnace pyrolizer, and the trapped air within the glass tubing was pumped out using a rotary vane vacuum pump before completely closing the furnace taps to ensure no exposure to the atmosphere. The pyrolysis was carried out at constant average heating temperature rise of 1.5°C per second; and average residence time of 2.5 seconds. After the pyrolysis, the outlet tap was opened to allow the gaseous vapors to exit through an air-tight water-cooled condenser to the U-tube manometer which was used to measure the total volume of the non-condensable gases that were produced. The furnace was subsequently cooled and the non-condensable gases were quantified by the displacement method using a U-tube manometer.

RESULTS AND DISCUSSION

The data for variation of biosynthetic gas yield with moisture and cellulose content is shown in **Figure 1.**

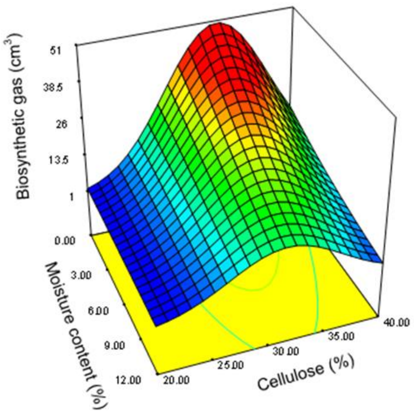

Figure 1: Variation of biosynthetic gas yield with moisture and cellulose content.

The data shows that for given cellulose content, the biosynthetic gas yield increased with decrease in moisture content. The highest value of biosynthetic gas yield (51 cm3) occurred at 0% moisture content. While for a given moisture content the biosynthetic gas yield increased with increase in cellulose content until a maximum value of biosynthetic gas yield at approximately 34% by weight cellulose content. This showed that within the experimental conditions, the optimum biosynthetic gas yield was 51 cm3 obtained at 34% by weight cellulose and 0% moisture content. A cellulose content of 34% was the average value when taking equal proportions of Arabica coffee and groundnut shells used as crop residues. This implies that a blend of Arabica coffee and groundnut shells gave the highest biosynthetic gas yield.

The data for variation of biosynthetic gas yield with moisture and average particle size is shown in Figure 2. The data shows that at constant average particle size, the biosynthetic gas yield increased gradually with increase in cellulose content. The highest value of biosynthetic gas yield (75 cm3 per 5 g dry weight sample) occurred at cellulose content of approximately 34% by weight, thereafter the biosynthetic gas yield decreased relatively sharply with further increase in cellulose content. Also, for a particular cellulosic content, the biosynthetic gas yield was approximately constant for all values of average particles sizes investigated. This implied that the biosynthetic gas yield was relatively unaffected by variations in average particle size.

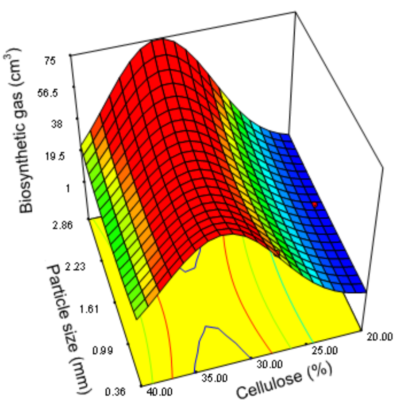

Figure 2: Effect of average particle size and cellulose content on the biosynthetic gas yield

There was also a highest minimum or saddle point observed from the data in **Figure 2** due to the interactive effect of average particle size and cellulose content. This occurred at an average particle size of 1.81 mm and cellulose content of approximately 34% by weight of dry sample. This implied that the minimum average particle size required for optimum biosynthetic gas yields was 1.81 mm.

The interactive effect of moisture content and average particle size on biosynthetic gas yield is shown in **Figure 3**.

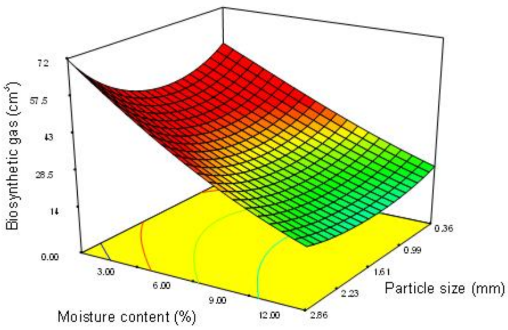

Figure 3: Effect of moisture content and average particle size on the biosynthetic gas yield

The data shows that for a given average particle size, the biosynthetic gas yield increases with decrease in moisture content, showing an inverse linear relationship between moisture content and the biosynthetic gas yield for a given average particle size. The highest value (12 cm3 of biosynthetic gas per 5 kg dry weight) was obtained at 0% moisture content. This implies that high biosynthetic gas yield was obtainable without the presence of moisture content in the biomass, for all values of average particle sizes. Secondly, for a given value of moisture content, the biosynthetic gas yield decreases with increase in average particle size until a minimum value observed at average particle size of 1.61 mm. The biosynthetic gas yield then begins to rise with increase in average particle size. The trend in increase appears to be faster at lower values of moisture content than at higher values. Consequently, the highest biosynthetic yields were obtained at highest average particle sizes that did not have moisture.

CONCLUSION

Basing on the experimental results, it was concluded that a blend of equal proportions of Arabica coffee and groundnut shells at 0% moisture content is suitable for optimum production of biosynthetic gas from the crop residues investigated. It was also concluded that the biosynthetic gas yield is relatively unaffected by variations in average particle size when considered alone. However, when considered together with cellulose content, it can be concluded that the minimum average particle size required for optimum biosynthetic gas yields is 1.81 mm when the cellulose content is 34% by weight of the dry sample. On the other hand, it was also concluded that the moisture content alone plays a less significant role in influencing the yield of biosynthetic gas, unless when considered in the presence of other parameters such as average particle size and cellulose content.

RECOMMENDATIONS

In view of the above conclusions, it was recommended that a blend of Arabica coffee and groundnut shells in equal proportions is the most suitable for production of biosynthetic gas from the investigated crop residues. Also, it was recommended that for optimum biosynthetic gas yield, the average particle size should be more than 1.81 mm for a cellulose content of 34% by weight dry sample. Last but not least, the moisture content should always be reduced to 0% by weight dry sample in order to generate optimum biosynthetic gas yields during the pyrolysis of crop residues.

ACKNOWLEDGMENT

This study was funded in part by the Swedish International Development Cooperation Agency (Sida) and Makerere University under Sida contribution No: 51180060. The authors would therefore like to extend sincere gratitude to the Management of Makerere University Directorate of Graduate Training (DRGT) for securing the fund; the Swedish Embassy in Uganda; and Management of Kyambogo University, Uganda.

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