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Bagasse Conversion to Hydrogen and Synthesis Gas by Gasification in the Presence of Oxygen and Water Vapor

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ABSTRACT– Hydrogen and syngas production from bagasse by gasification in the presence of water vapor and oxygen is studied. The effect of steam to bagasse ratios (0.4, 0.6, 0.8 and 1) and oxygen to argon ratio (0.1, 0.15, 0.2 and 0.25) on gasification yield were investigated under identical conditions (reactor temperature of 850oC, reaction time of 30 min and bagasse content of 1 g). The operating conditions were optimized for oxygen to nitrogen ratio of 0.15 and steam to bagasse ratio of 0.8, due to the production of a gas richer in hydrogen and carbon monoxide and poorer in carbon dioxide and hydrocarbons. The maximum syngas yield of 83.11 g/ kg-bagasse with composition of 63.22 vol% H2 and 25.08 vol% CO is achieved.
Keywords: Bagasse, Gasification, Hydrogen, Syngas, Oxygen, Steam

Introduction

Today, supplying energy is one of the major problems of human life. In fact human for achieving welfare could make tools and equipments with using knowledge that by energy consuming provides comfort. [1][2][3][4] Renewable energy technologies are clean sources of energy that had less environmental impact than other common energy technologies. Renewable energies, had better compatibility with nature and environment, their production have little environmental pollution. Renewable energy comes from 3 major sources that are: sun (solar, wind, wave, biomass, hydroelectric, hydrogen and fuel cell), earth (geothermal, piezoelectric) and the moon (tides). Today, using renewable energy is growing in the world so that renewable power generation in the last 10 years is reached from 3.24TWh to approximately 5.5TWh. The percentage of power generation from biomass energy is reached from 1.1 to 1.9 in 2014 that with improvement of biomass conversion technologies it can be expected fast growth of power generation. Data show that from 2004 to 2012, renewable energies cover 22.4 percent and biomass energy has been exploited 1.1 percent to 1.8 percent of the total renewable energy over the years. Waste and residues of agricultural, gardening and woodsy products, livestock waste, biodegradable municipal waste, municipal wastewater and industrial waste are different types of biomass that can be converted to energy.[5][6][7][8][9][10] The purpose of this research is achieving to the most production of hydrogen gas and synthesis gas from bagasse biomass in gasification system in the presence of water vapor and oxygen simultaneously. Hydrogen is a clean and excellent fuel for the future of world's energy and it is necessary to investigated production methods, maintenance and use of them.[11][12][13][14]

Research methodology

The bagasse biomass as feedstock was supplied from Haft-Tappe Industries. The material was washed, grinded and sieved to achieve particle sizes up to 1 mm. The CHNSO analysis was performed for mass fraction determination of C, N, H, S and O bagasse structure. Figure 1 shows the reaction setup. As shown, the reaction was performed in a fixed bed reactor made of a quartz glass tube with 800 mm long and 10 mm internal diameter. Quartz wool and feed were fixed in center of the reactor. The reactor was located inside a tubular furnace with 20mm ID and 200mm OD with total heating length of 700mm. Furnace temperature was controlled using an electrical heater and a PID temperature controller and measured using a K-type thermocouple. Brook's mass flow controllers were used to inject oxygen and Argon to the reactor. Argon was used as inert carrier gas with exactly 30ml/min flow rate and Oxygen to Argon ratios were 0.1, 0.15, 0.2 and 0.25. Water was injected to the reactor using a syringe pump with water vapor to bagasse ratios of 0.4, 0.6, 0.8 and 1. Reaction time, bagasse weight and reactor temperature were 30 min, 1 gr and 850°C, respectively. The product leaving the reactor was condensed and separated into liquid and gaseous fractions. The liquid fraction was collected in a liquid trap of ice-salt bath and the gaseous fraction was collected over a sodium chloride saturated brine solution in a graduated column. The volume of collected gases was measured from displacement of the solution in column. The reactor was allowed to cool down at the end of each experiment. The quality and quantity of produced gaseous mixture were analyzed using gas chromatography technique (Varian 3400 and Teyfgostar-Compact). The condensed tar in glass condenser and char left inside the reactor were measured by measuring the difference in weights of glass condenser and reactor before and after the reaction. All experiments were repeated twice under the same experimental conditions and the data reported herein are averages of repetitive runs.

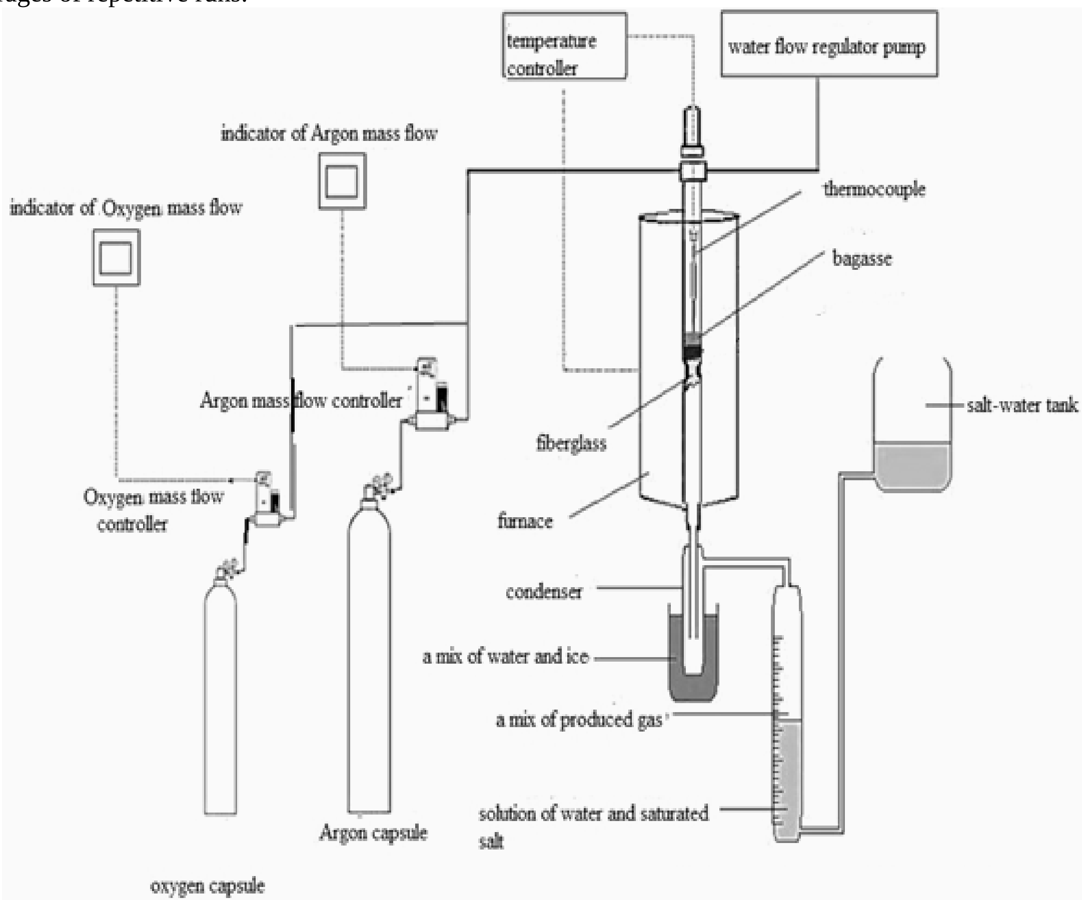


Figure 1: Gasification experimental setup

Results and Discussion

The CHNS analyses of the biomasses were N = 0.69%, C = 58.10%, H = 6.45%, S = 0.19% and O = 34.57%. The C and H content in the sample was 64.55%. The balance was mostly oxygen.

The effect of water vapor to bagasse ratios (0.4, 0.6, 0.8 and 1) and oxygen to argon ratios (0.1, 0.15, 0.2 and 0.25) on gasification yield through gasification via reforming of bagasse were investigated under identical conditions (reactor temperature of 850ºC, reaction time of 30 min and bagasse content of 1 g).

Effect of water vapor to bagasse ratio

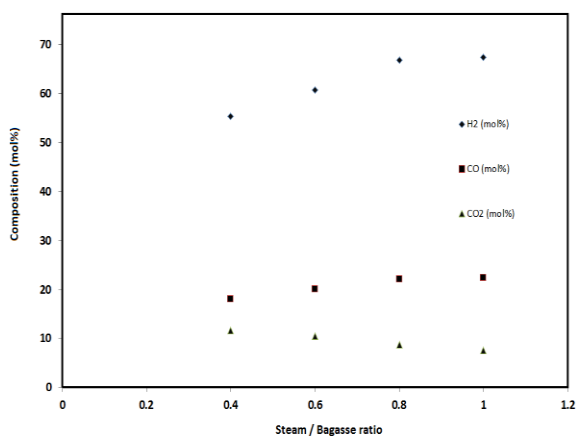
It has been shown that, gasifying agent has significant impacts on the gasification reactions. Oxygen and water vapor increase the heating value of the produced gas. By using a mixture of oxygen and water vapor, the quality of the syngas and overall syngas yield will be enhanced. Biomass conversion to syngas in pyrolysis and gasification processes occurs under the main steps that are indicated by the following reactions:

Biomass$\rightarrow$ Gas+Tars+Char (1)
Tars$\rightarrow$Light and Heavy hydrocarbons+CO+CO_2+H_2 (2)
Heavy hydrocarbons$\rightarrow$Light hydrocarbons+H_2 (3)
Char$\rightarrow$$CO$+$CO_2$+$H_2$+Solid residual (4)

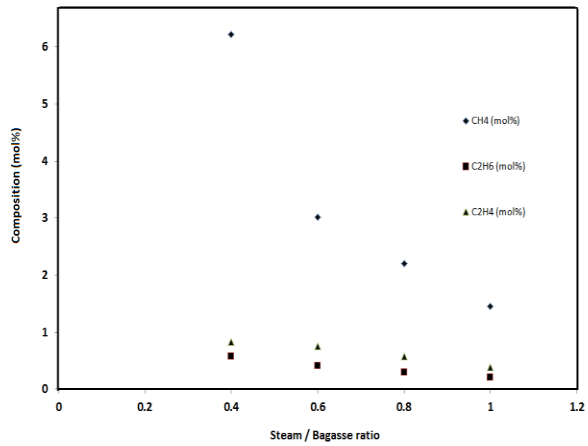
The formation of CO, CO_2, and CH4, H_2 via pyrolysis and gasification processes can be studied through the given reactions in equations 5–13 that occur at various degrees.

$C+1/2O_2 \rightarrow CO$ (5)
$C+O_2 \rightarrow CO_2$ (6)
$C+CO_2 \rightarrow 2CO$ (7)
$C+2H_2 \rightarrow CH_4$ (8)
$C+H_2O \rightarrow CO+H_2$ (9)
$CO+H_2O \rightarrow CO_2+H_2$ (10)
$CH_4+H_2O \rightarrow CO+3H_2$ (11)
$CH_4+CO_2 \rightarrow 2CO+2H_2$ (12)
$C+2H_2O \rightarrow CH_4+CO_2$ (13)

Figures 2 and 3show the gasification yields (mmol of gas/g of bagasse) for the H_2, CO, CO_2, CH_4 and heavier hydrocarbons at constant oxygen to argon ratio of 0.1and different water vapor to bagasse ratios. As shown, the water vapor to bagasse ratio is an influential parameter on the gasification process and is important to find the existing optimum point in the conversion process since too large water vapor to bagasse ratios do not always favor the syngas production and is not cost effective. By enhancing the conversion reactions via injection of steam, reforming reactions, water gas shift and char gasification become the governed reactions in the overall biomass conversion process and causes an increase in the syngas production. By increasing water vapor to bagasse ratio from 0.4 to 0.8, the syngas yield increased to a maximum value of 81.24 g/ kg-feedstock and then slightly smoothed. The composition of syngas at this point was 66.84 vol% H2 and 22.09 vol% CO. On the other hand, CH_4 and CO_2 content showed a decreasing trend due to reactions (7), (11) and (12). The H_2/CO ratio increased to 3.03 and also CO/CO_2 ratio showed an increasing trend from 1.53 to 2.98. The steam to bagasse ratio of 0.8 was selected as the optimum value of this parameter and next experiments were done with constant steam to bagasse ratio of 0.8.



Figures 2: Variation of the gasification yields (mmol of gas/g of bagasse) for the H_2, CO, CO_2 with steam/bagasse ratio.

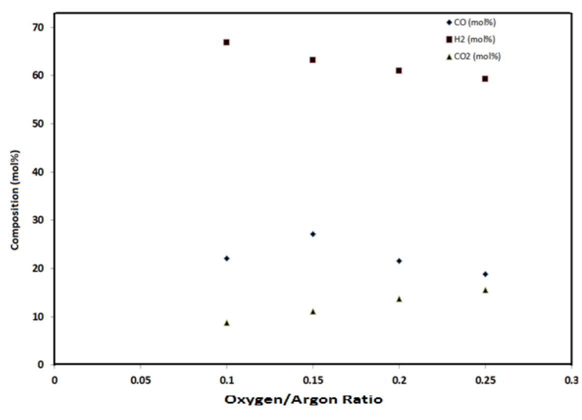


Figures 3: Variation of the gasification yields (mmol of gas/g of bagasse) for the CH_4, C_2H_6, and C2H4 with steam/bagasse ratio.

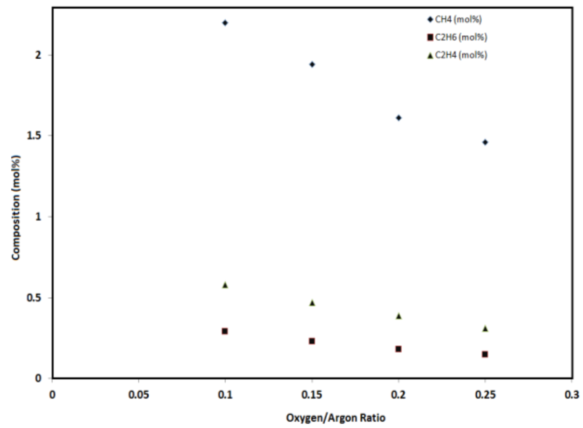
Effect of O_2/Ar ratio

The results of parametric O_2/Ar ratio tests for bagasse biomass are presented in Figures 4 and 5. Oxygen to argon ratio was increased from 0.1 to 0.25 at constant steam to bagasse ratio of 0.8. Increasing O_2/Ar ratio resulted in the production of a larger volume of gas. Also, a strong influence of O_2/Ar ratio on the product gas composition is observed. It seems that higher partial pressure of O_2 in the reactor favors the tar cracking reactions, producing more light hydrocarbons and other gas phase products. As shown, H_2, CH_4 and other light hydrocarbon concentrations decreases with increasing O_2/Ar ratio. CO_2 concentration increased with increasing O_2/Ar ratio, while CO concentration increased significantly with increasing O_2/Ar ratio, passed through a maximum at O_2/Ar ratio of 0.15 and then started to decrease. The maximum syngas yield of 83.11 g/ kg-feedstock is achived at this condition. It seems that in the first stage (O_2/Ar ratio of 0.1–0.15), reaction (5) was more likely to occur than reaction (6) because of the lack of oxygen. Reaction (6) consumes 0.5 mol more oxygen than reaction (5). Therefore, oxidation reactions of tars, char and combustible product gases became more important in the second stage (O_2/Ar ratio of 0.15–0.25) which in turn leads to higher concentration of CO_2 and lower concentration of CO at high values of O_2/Ar ratio.

Through the analysis on the experimental data of varying O_2/Ar ratio, it can be understood that it is unfeasible to apply too small or too large O_2/Ar ratio in bagasse biomasses gasification to produce H_2 and syngas. Too small O_2/Ar ratio will lower the total product gas and too large O_2/Ar ratio will consume more H_2 and other combustible gases through oxidization reaction and decrease the CO/CO_2 ratio. So, there exists an optimal value for O_2/Ar ratio, which can be different for different biomasses. In the present study, the optimal value of O_2/Ar ratio was found to be 0.15 for bagasse biomasses.



Figures 4: Variation of the gasification yields (mmol of gas/g of bagasse) for the H_2, CO, CO_2 with Oxygen/Argon ratio.



Figures 5: Variation of the gasification yields (mmol of gas/g of bagasse) for the CH_4, C_2H_6, C_2H_4 with Oxygen/Argon ratio.

Conclusion

Gasification of bagasse in the presence of oxygen and water vapor was successfully carried out, producing a gas with considerable H_2 and CO concentrations which could be employed in many end-use applications. The operating conditions were optimized for oxygen to nitrogen ratio of 0.15 and steam to bagasse ratio of 0.8, due to the production of a gas richer in hydrogen and carbon monoxide and poorer in carbon dioxide and hydrocarbons.

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