Comparative Studies of the Energy Properties for *Prosopisjuliflora* and Rice Husks (*Oryza sp.)* as Feedstock for Renewable Energy Generation

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Abstract: ***Management of Agricultural wastes especially rice husks and the invasive weed species Prosopisjuliflora which has seen massive invasions in many areas in Kenya presents great challenges to the environment. Rice husks are a key byproduct of rice production that's not considered of economic value and since they do not biodegrade easily they pose a waste management issue in many of the rice growing regions in Kenya. The invasion of P. julifrora in most parts of Kenya has resulted in a myriad of social and ecological concerns. Even though investment in its control has been an issue for over a period of time now since the invasion, recent studies show potential of using it to produce bio-energy. The objective of the study was to carryout comparative studies on the potential for utilization of Rice husks and P. juliflora as a renewable energy resource for energy production. Chemical composition of Syngas was carried using Fourier Transform Gas analyser(Matrix – MG from Bruker) to determine the composition of the syngas. Co-firing of P.juliflora and rice husks was also assessed. Syngas from rice husks was found to be composed of 17.05 ± 0.21 % CO, 15.7 ± 0.14 % CO2, 4.3 ± 0.00 % H2, 7.35 ± 0.07% CH4 and 28.1 ± 0.42 % N2 among others while Syngas from Prosopis was found to be composed of 21.15 ± 0.91 % CO, 13.15 ± 0.50 % CO2, 19.25 ± 0.07 H2, 5.45 ± 0.07 CH4 and 40.585 ± 0.19 % N2 among others. Finally Syngas from co-firing of the two feedstocks was found to be composed of 18.37 ± 0.45 % CO, 12.77 ± 0.21 % CO2, 15.4 ± 0.3 H_2, 8.87 ± 0.35 % CH_4 and 32.6 ± 0.56% N_2 among others.***

Keywords: Bioenergy, Gasification, Syngas, feedstock

1. Introduction

Kenya's demand for energy has been growing steadily over a period of time. According to theG.o.K (2014)[1], the peak demand for electricity is projected to grow from 1,354MW as at June 2013 to 3,400MW by 2015 and to 5,359MW by 2017. In order to meet this demand, a new additional generation of about 5,000 MW needed to be developed by the end of 2016 to bring total installed capacity to at least 6,600MW. It is also projected that the annual energy consumption will increase from 8,087GWh in 2012/13 to 32,862GWh in 2016/17 and that by 2030, peak demand will be 18,000MW against an installed capacity of 24,000MW. In Kenya electricity supply is predominantly sourced from hydro and fossil fuel (thermal) sources. The current generation energy mix comprises about 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from biogas cogeneration and 0.4% from wind, respectively G.O.K (2014) [1]. To meet this demand, Kenya's installed capacity should increase gradually to 19,200 MW by 2030. Mugo.F (2010) [2]and Nelly (2013)[3]Noted that biomass energy provides about 68% of Kenya's national energy requirements both in most rural and urban areas and it is expected to remain so for a long period of time. In the year 2000, Kenya was reported to use about 34.3 million tonnes of biomass for fuel of which 15.1 million tonnes was in form of fuel wood while 16.5 million tonnes was wood for charcoal processed in kilns with only 10% efficiency. Muzee, (2012) [4] noted that Up to 43% of the national wood biomass consumption was from sustainable supplies while 57% was from unsustainable supplies. Of Kenya's total land area of 57.6 million hectares, only 6% (3,456,000) is forest cover and is estimated to be decreasing at the rate of 52,000 hectares (0.09%) per year. He further notes that in 1980, 94% of all the wood harvested in the country was used for wood fuel, 4% for poles and 2% for timber. By 1997, the proportions were estimated to be 90% wood fuel, 5% for industrial feedstock and another 5% for poles and posts.

This research tries to explore alternative means of providing cheap and readily available energy for the use at the rural setups by using the readily available biomass resources in this case the prolific weed *prosopisjuliflora* and agricultural wastes. This form of renewable energy can contribute tremendously to the provision of safe and sustainable energy and contribute to the development agenda. According to UNEP (2016) [5], in most developing countries a lot of time is spent especially by women incollecting biomass-based energy supplies which is mostly responsible for tremendous time poverty and foregone opportunities in many sectors. According to Basu, (2010),[6]Biomass is able to deliver nearly everything that fossil fuels are able to provide either fuel or chemical feedstock. In addition it also provides very important benefits that make it a viable feedstock for syngas production. When burnt, it does not make any net contribution to the atmosphere and secondly its use significantly reduces dependence on nonrenewable and often imported fossil fuels which are polluting and expensive.

2. Prosopis as an energy resource

Kenya has had several invasions of alien species that have had negative impacts on biodiversity, agriculture, energy and human development. Mostly management strategies that are employed in the country have included quarantine measures for unintentional and intentional introductions, eradication, containment and control, monitoring and research, regional cooperation and public awareness. More research, cooperation, assistance and capacity building is required to effectively manage the problem of invasive species by using them as alternative sources of energy to contribute to the improvement of energy security in Kenya.

In most cases invasive species in the dry areas and mostly in the rangelands of East Africa have been introduced both intentionally and accidentally and are damaging the natural and man-made ecosystems affecting community livelihoods. Obiri (2011)[7]notes that "In East Africa, and particularly Kenya, pastoralists have been adversely affected and disasters registered in many communities. For instance, in 2006, following the heavy livestock losses caused by the invasive plant *P. Juliflora*, communities of Baringo, Kenya, instituted a constitutional case against the government of Kenya for introducing it in their environmentG.o.K (2007)[8]. The communities pointed out a pack of disasters that befell them as a result of the prosopis weedG.o.K (2007)[8]. These include the lack of water around Lake Baringo due to the colonization of the weed on the lake shores and human diseases such as asthma, lung inflammation and allergies". According toChoge (2004)[9]These effects of the invasive weeds have made them seem as if they are beyond control and in most cases they have not been put into other productive uses.

3. Rice husks as an Energy Resource

Rice husks have also posed a number of challenges for many rice millers. According toNjogu (2015)[10], Rice husks are a key byproduct of rice production that does not have any economic value to the millers. He further notes that the direct use of rice husks as an energy source is hampered by low density and low heat value. It is thus imperative to convert it into combustible gas. According toRajvansh (2013)[11] Rice husks contain 75% organic volatile matter and 25% ash. Rice husks can be converted thermally, biologically or chemically to other usable forms of energy like methane gas, liquid fuels (ethanol) and syngas/process gas. This makes it necessary to come up with innovative ways of sustainable utilization of such wastes. The current practice is open burning which leads to transfer of pollutants from land to the atmosphere

4. Materials and Methods

4.1 The Study Area

The study was carried out at JomoKenyatta University of Agriculture and Technology (JKUAT), Institute of Energy and Environmental Technology (IET) research laboratories. Samples of Prosopis were collected from Baringo area where the tree shrub is highly prolific and the samples for rice husks were collected from the rice growing regions (specifically in Mwea Rice Irrigation scheme), where management of the rice husks poses a great agricultural waste management problem.

4.2 Sample Collection

Samples were taken from *P.Juliflora* Stands in Baringo district in Kenya using manual methods. The rice husks were also collected from the rice growing areas in Mwea region in Kenya. Samples were collected and sun dried to around 10% for Prosopis and 9% for the rice husks The Moisture content for the samples were determined using an oven by using the following procedure. One gram of the biomass was weighed into a crucible and placed in an oven set at 105^0 C for 24 hours. The sample was dried to constant weight. The sample was then weighed and the mass difference calculated. This value was used to determine the moisture content.

4.3 Research Design

The study was carried out at JKUAT research laboratories. This study was designed as an experimental study design to which endeavored to study energy properties specifically gas composition of *Prosopisjuliflora* and rice husks including the effect on co-firing during the gasification process;

4.3.1. Determination of syngas composition from the gasification of of *P.Juliflora* and rice husks.
The activities under this objective entailed determining gas composition of *P.Juliflora* biomass and rice husks. The results of the two biomass types were then be compared

4.3.2. Determination of the effects of co-firing *P.Juliflora* and rice husks.
This entailed determining the effects of co-firing using the two types of biomass. This involved mixing and co-firing them in the ratio of 1:1of the two types of biomass under study and compared the results obtained.

4.4 Determination of the Chemical composition of syngas

Gas samples obtained from the gasification process were collected using gas balloons and transported to the laboratory for analysis. The gas compositional analysis was done using a gas Analyzer Matrix – MG from Bruker coupled with a comprehensive software package **OPUS GA (Gas Analysis).** The target gas is measured in a gas cell for high sensitivity compound analysis based on (Fourier Transform Infra-Red) FT-IR spectroscopy. From the obtained spectra the gas concentrations are retrieved automatically by a nonlinear fitting procedure within the comprehensive software package, without the need for gas calibrations.

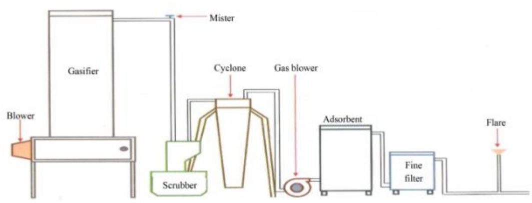

Figure 1: The gasification system

After gasification the raw syngas, laden with contaminants in form of particulate matter and tar exits the reactor to enter the water scrubbing system where it is cooled and conditioned to a level that is acceptable for engine operations or direct use, also carbon dioxide is removed at this stage. The gas then enters the cyclone separator which helps to remove tars and suspended particles. Water vapor is then removed in the next stages by the adsorbent material. The gas finally passes through a fabric filter prior to flowing to the gas engine to remove finely suspended particles.

5. Results

5.1 Gas Composition of *P.juliflora* and Rice husks

Gas samples were collectedin triplicate after the gasification process for the two feedstocks under study and the gas composition analysed using a gas anlyser (Matrix MG from Bruker).
The results were documented in the following table (table 1)

Table 1: Percentage Mean ± SD of the syngas components from the two feed stocks

Component	% Mean ± SD for each of the Syngas components for Rice Husks and *Prosopis*	
	Rice Husks	Prosopis
H_2	4.3 ± 0.00	19.25 ± 0.07
CO	17.05 ± 0.21	21.15 ± 0.91
CO_2	15.7 ± 0.14	13.15 ± 0.50
O_2	0.1 ± 0.01	0.165 ± 0.02
CH_4	7.35 ± 0.07	5.45 ± 0.07
N_2	28.1 ± 0.42	40.585 ± 0.19
Others	27.4 ± 0.83	0.25 ± 0.35

The focus of this research was mainly on the flammable gases H_2, CO and CH_4 which are very important in determining the calorific value of the syngas from the gasification process.

In comparison it was found out that rice husks had a lower hydrogen concentration (4.3 ± 0.00 %) compared to prosopis which had a higher concentration of (19.25 ± 0.07 %). Rice husks had also a lower carbon monoxide concentration of 17.05 ± 0.21 % compared to prosopis which had 21.15 ± 0.91 %. Prosopis had lower Methane content of 5.45 ± 0.07 % compared to rice husks which had a higher concentration of 7.35 ± 0.07 %.

5.2 Determination of the effects of Co-firing rice husks and prosopis feedstocks

The two feedstocks were co-fired in the ration of 1:1 and the gas collected for analysis. Several tests of co-firing were conducted and the results tabulated in table 2 below;

Table 2: Results of co-firing rice husks and prosopis

	% Mean ± SD for each of the Syngas components for the three biomasses		
	Rice Husks	Prosopis	Co-firing results
H_2	4.3 ± 0.00	19.25 ± 0.07	15.4 ± 0.3
CO	17.05 ± 0.21	21.15 ± 0.91	18.37 ± 0.45
CO_2	15.7 ± 0.14	13.15 ± 0.50	12.77 ± 0.21
O_2	0.1 ± 0.01	0.165 ± 0.02	0.203 ± 0.03
CH_4	7.35 ± 0.07	5.45 ± 0.07	8.87 ± 0.35
N_2	28.1 ± 0.42	40.585 ± 0.19	32.6 ± 0.56
Others	27.4 ± 0.83	0.25 ± 0.35	11.79 ± 0.54

On average co-firing yielded interesting results and these wereas illustrated in figure 2 below which shows trends in gas composition using the three biomass samples;

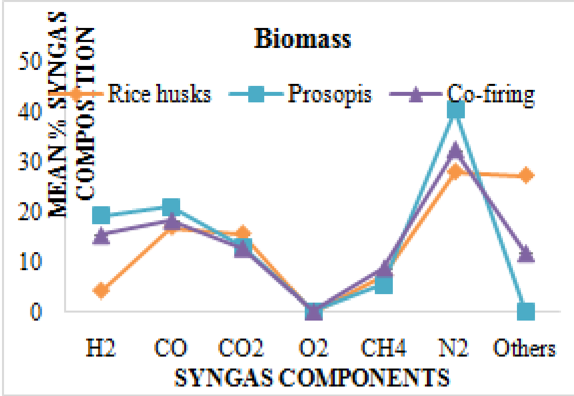

Figure 1: Trends of the mean % composition of various gaseous components for rice husks, prosopis and co-firing results

It was found out that Prosopis had the highest concentration of Hydrogen gas at 19.25 ± 0.0707 % compared to Rice husks 4.3 ± 0.0000 %. When we co-fire the two feed stocks it was found out that hydrogen production was improved compared to using rice husks alone to around 15.4 ± 0.3 %. The same applies to carbon monoxide gas where by Prosopis had the highest concentration of 21.15 ± 0.9192 % compared to rice husks which had 17.05 ± 0.2121 % but when we co-fire them we obtain an average of 18.37 ± 0.4509 %. Most interesting results were for Methane gas whereby Prosopis had the lowest at 5.45 ± 0.0707 % compared to rice husks at 7.35 ± 0.0707 % but when we co-fired the two feed stocks the methane gas percentage went up to 8.87 ± 0.3512 %.

Multiple Comparisons using Analysis of Variance (ANOVA) at 95% Confidence Level (significance at the 0.05 Level)

(Biomass)		Significance at the 0.05 confidence level			
		H_2	CH_4	CO	CO_2
Prosopis	Co-firing	0	0	0.013	0.416
	Rice husks	0	0.004	0.004	0.002
Co-firing	Prosopis	0	0	0.013	0.416
	Rice husks	0	0.006	0.132	0.001

There was an increase in the % composition of Hydrogen in both prosopis and co-firing Prosopis/rice husks as compared to rice husks. The % composition of H_2 in the syngas was highest in Prosopis, followed by co-firing rice husks and prosopis and lastly rice husks. All three biomasses showed a significant difference in the % composition of H_2 in the syngas composition amongst each other.

The % composition of CH_4 in the syngas was highest in co-firing rice husks/prosopis, followed by rice husks. Prosopisshowed the least % composition of CH_4 in the syngas. There was a significant difference in the % composition of CH_4 in the syngas for all the three biomasses.

The % composition of CO in the syngas was highest in prosopis, followed by cofiring rice husks/prosopis. Rice husks had the least % composition of CO in the syngas.

However, there was no significant difference in the % composition of CO in the syngas for rice husks and co-firing rice husks and prosopis.

There was a decrease in the % composition of CO_2 in the syngas from rice husks, prosopisto co-firing rice husks/ prosopisin that order. However, there was no significant difference in the % composition of CO2 in the syngas for prosopis and co-firing rice husks/prosopis.

The % composition of N2 in the syngas was highest for each of the three biomasses. All the three biomasses showed a significant difference in the % composition N_2 in the syngas.

The % composition of other gases in the syngas reduced significantly from rice husks to the other two biomasses. Prosopis showed the least % composition of other gases in the syngas while rice husks had the highest. There was a significant difference in the % composition of other gases in the syngas for all the three biomasses.

6. Conclusion

From the study it is evident that biomass gasification offers one of the most promising renewable energy systems for developing countries especially Kenya where there are readily available feedstock like the highly prolific *Prosopis sp.* and rice husks from the rice growing regions at very minimal costs.

Co-firing of the various feedstocks produces quality syngas which could be used for a variety of applications especially in the off-grid areas to produce cheap electricity and power the local villages where access to electricity is still an issue. Large scale gasification systems are possible for electricity generation which can be fed directly to the grid to provide cheap and reliable electricity to the country. Being comparatively easy to build with low cost materials, downdraft gasifiers could be an attractive technology for thermal and power applications in most developing countries.

Gasification of the invasive weeds and agricultural wastes is one of the best options for managing them as opposed to the other eradication and disposal mechanisms which are costly and do not offer value addition to the affected communities. Using them to produce energy is the most cost effective option.

7. Acknowledgement

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