Characterization and energetic value of peat from the highland of Rwanda

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Abstract: Rwanda has estimated reserves of 155 million tons of dry peat spread over an area of about 50,000 hectares. However, the quality of the peat is still unknown, and the peat bogs are still unexploited or poorly exploited. It is in that regard an experimental study was undertaken to analyse the quality of peat in the northern high land of Rwanda. Composite peat samples were systematically collected in each of four peat bogs in the region: Bisika, Bahimba, Ndongozi and Nyirabibande. After moisture estimation and natural drying, samples were subjected to proximate (still wet as received) and ultimate (dry ash free) pyrolysis. In order to determine the composition of the char collected from the samples at the end of the previous experiment, the same process of pyrolysis was undertaken. The results found after proximate pyrolysis revealed that the peat samples contain higher amounts of volatile matter between 60-70%, and less fixed carbon than indonesian high-moisture bituminous coal and Mongolian lignite in a dry condition. Also according to an ultimate analysis, peat contains more oxygen by about 10% than low-rank coal. The results from proximate and ultimate pyrolysis also revealed a significant difference in terms of Moisture (M), ash, fixed carbon (C), Hydrogen (H), Oxygen (O), High Heating Value (HHV) and Low Heating Value (LHV); between peat bogs samples. Thus, according to energy patterns in Rwanda, peat briquetting or hybrid peat pellet for household/industry is highly recommended.
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Introduction

In the absence of affordable modern fuels and electricity, 90% of the Sub-Saharan African population relies on traditional fuels for cooking, heating and lighting (Wolde-Rufael et *al*, 2009). In Rwanda, the energy sector includes electric power, petroleum and Biomass sub-sectors. Biomass dominates the country energy consumption with an average of 85% of total national consumption broadly for household heating and cooking needs. Petroleum products and hydropower occupy respectively 11% and 4% of total national energy consumption (Edwin et *al*, 2012)**.** Most of the population in Rwanda consists of smallholder subsistence farmers who produce most of their own food on one hectare or less. These farmers critically depend upon local ecosystems for survival and are directly affected by changes in availability of ecosystem goods and services, such as water, medicinal plants, firewood, and raw materials for building (Ali and Deininger, 2015).

Efficient use of biomass energy is of great interest since biomass is a sustainable and renewable energy resource and it includes every type of carbonaceous materials except fossil (Klass, 1998)**.** The rate of biomass consumption in Rwanda is unsustainably driven by population growth leading to rapid to a high rate of deforestation. Wood fuel constitutes 90% of rural energy consumption. The balance 10% is met by other options such as agricultural residues, fuel, charcoal, grid and non-grid electricity, peat, gas, solar and other renewable energies. Wood and charcoal energy is used by 98.7% of the population for cooking and by 17.7% of the population for light (Safari, 2010)**.** The study carried out revealed that the biomass is already in short supply and the country is facing a biomass deficit of over 4 million cubic meters per year (Landi, 2013)**.** It was also reported that the primary energy balance in Tons Oil Equivalent (TOE) highlights the chief role of biomass and the low contribution of modern energy in the energy sector in Rwanda (Jean de Dieu et al, 2016). This could predict the country's energy poverty and predictable forest depletion due to biomass dependence. The per capita final energy consumption is as low as o.13TOE, while in OECD countries, the average is 3.10 TOE per capita (EUEI, 2011)**.** To address the above mentioned problem, the government of Rwanda has prohibited the use of firewood for brick and tile making in 2004. Different factories have switched to coffee and rice husks, and other biomass. It was estimated that some 115,000 tons of maize residue is produced annually as well as 13,000 tons of rice husks and 5,500 tons of coffee husks. The latter two are in high demand by small-scale industries, such as brick and tile producers. For household use, these fuels are now difficult to obtain and are fully used by cottage industries that are no longer allowed to use wood (Dasappa, 2011; Jamvier et *al*,2016). The briquetting of biomass has been known for over century. To date, different dependencies and parameters have already been obtained and defined to provide strong briquettes. However the following problems are still to be addressed in this field:

-high energy intensity of production due to the use of energy-intensive pressure equipment.

-low humidity resistance of briquettes or none at all.

-the calorific value of briquettes depends on the characteristics of raw materials which sometimes do not allow obtaining the briquettes that would meet the standards (Zhang et *al*, 2008; Troshin,2010).

In contrast, Rwanda has substantial reserves of peat as a natural resource that was estimated to 155 Million tons of dry peat spread over a 50,000 ha area under the ground (Jean de Dieu, 2016**).** So, it is highly needed to use the peat resources to develop the alternative fuel energy for replacing the firewood. Nonetheless, those million tons of peat reserved under the ground can be exploited and finished in certain period of time. Hence there is a need to characterize the peat bogs in Rwanda in order analyse how they can be supplemented by with biowastes ingredients such as farm wastes, Oxisols etc to produce hybrid of peat pellets (Brigwater,1999**)**. It is in that regard an experiment study was undertaken to assess and compare the fuel characteristics of Bahimba, Nyirabirande, Ndongozi and Bisika peat bogs in the highland of Rwanda for efficiently and improved use for household as well industrial level. Biomass fast pyrolysis is of rapidly growing interest in Europe as it is perceived to offer significant logistical and hence economic advantages over other thermal conversion processes. This is because the liquid product can be stored until required or readily transported to where it can be most effectively utilized (Gilman and Dobos, 2011**)**.

Research materials and methods

The present experiment focused on evaluating peat collected from Bisika and Bahimba Peat bogs in Rulindo; Ndongozi and Nyirabibande peat bogs in Burera district, northern Rwanda.

Fig. 1: **Texture and structure of experimental Peat bogs**

Composites peat samples were systematically collected in each of those above mentioned peat bogs (Fig.1). At each 50 meters interval all over each peat bog, a soil profile was created and the peat subsamples were taken along the profile and mixed together to make composites samples representing thoroughly every peat bog as observed on figure1 above. The collected samples were then thoroughly covered and transported to the experimentation site of UR-CAVM Busogo, whereby one part of peat samples were air dried naturally up to 10% -2% of moisture content while another part was thoroughly covered and kept in the refrigerating room temperature. After drying both parts of the samples were immediately sent in the peat laboratory of the Korean institute of energy resources (KIER) in order to analyse the fuel characteristics through pyrolysis process. The process consists of heating the peat to a proper temperature and recovering the products which are emitted from the process. The pyrolysis, generally, produces various gases which are withdrawn from the particulate and a mist of liquid droplets (char) which further is subjected ultimate pyrolysis (Kaliyan, and Morey,2010; IEA,2015). These samples were kept in open trays to get air-dried specimens and then the particle size was reduced to lower than 250 µm by milling and sieving. From the samples, analysis was undertaken to asses moisture content (M), volatile matter (VM) while Ash and fixed carbon were calculated on a dry basis in each case. The HHV and low heating value LHV were also investigated. Among the peat samples collected from the four peat bogs, the sample with the highest calorific value was subjected to indirect pyrolysis (Bridwater, et a*l*, 199; Gilman and Dobos, 2012). Since peat is a fuel containing substantial volatile matter, a coal gas power generation technology based on direct pyrolysis was tested (Fig.2) (Held, 2014).

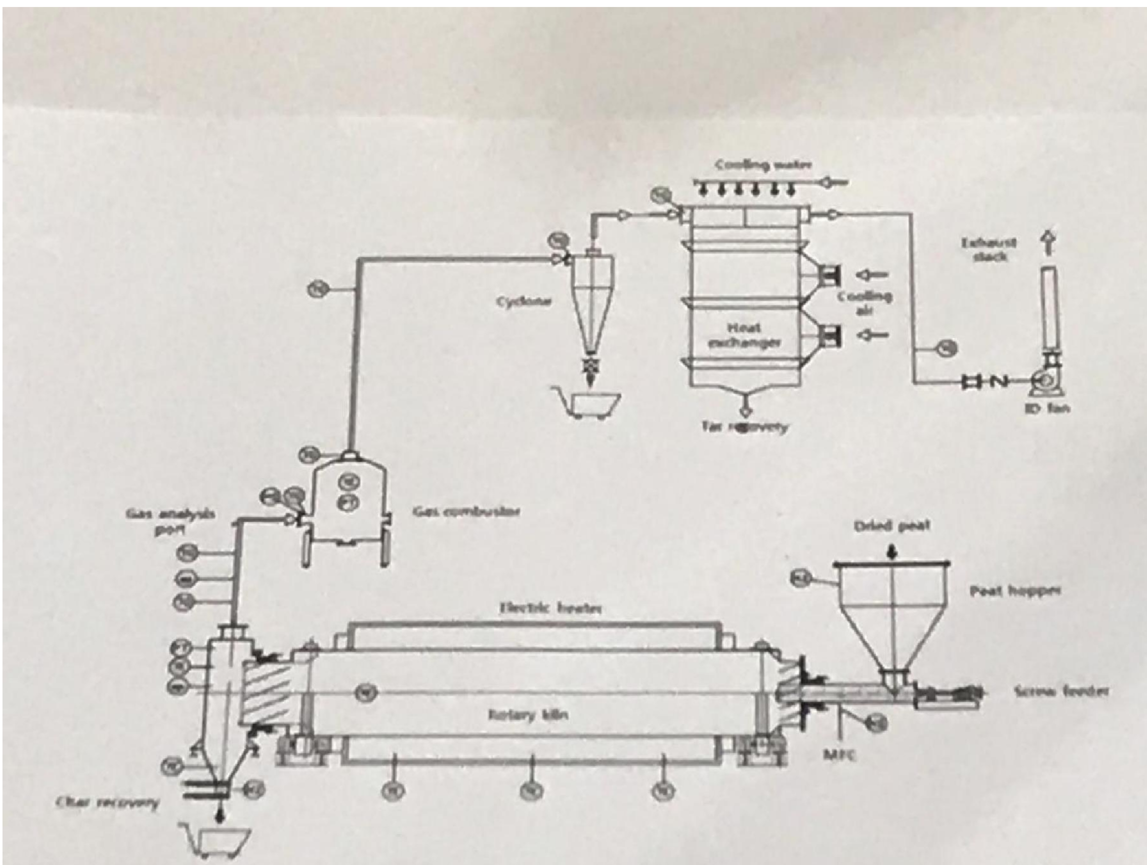

Fig. 2/3 Configuration of the peat pyrolysis system

With the surface of the shell that is heated to a high temperature from inside, and as ıt moves toward the outlet, ıt ıs gradually drıed and pyrolyzed. Syngas and tar generated at thıs tıme are combusted ın the gas combustor and dıscharged through the cyclone, the heat exchanger, and the stack. The pyrolysis T^0 of the rotary kiln reactor was 600° C, and in consideration of retention time, the gas was collected three times for 5 minutes after 60 minutes of peat input. The pyrolyzed char is then recovered at the outlet of the kiln. In thıs experıment, only a small amount of peat was available; therefore atotal of 12kg (8kg/hr speed) was supplied to the hopper and pyrolyzed continuously for about 90 minutes. The retation time of the peat in th reactor was 1hour. Also to create an inert atmosphere inside the reactor during pyrolysis process, a separate N_2 supplier was installed to supply N_2 inside the reactor (Xu et *al*,2015). In a controlled atmosphere, the peat sample was consistently measured as a function of temperature; fixed carbon was measured directly, as was the range of medium volatile matter and ash. The method of calculating the heat values by using data derived from ultimate analysis was also employed. Percentage values of carbon, hydrogen, oxygen, nitrogen, and sulfur, all determined by elementary analysis, as well as moisture and ash values, were used to calculate calorific values (Miles,2015).

Presentation and discussion of results

Fuel characteristics of Peat samples

The results of analyses of peat randomly sampled from four peat bogs d namely, Bisika, Bahimba, Ndongozi and Nyirabirande showed that the characteristics of Rwandan peat differ from region to region (table1) below. The results of analysis of peat randomly sampled from Bisika, Bahimba, Ndongozi and Nyirabibande in Rwanda, revealed that Rwandan peat shows different characteristics from site bog to site bog. According to a proximate analysis of the sample, moisture accounted for more than 80% on average. It was also found that more than 90% of peat from Ndongozi with the highest calorific value of 5,100kcal/kg was a volatile matter, with 8.5% of it being ash. On the other hand, a sample of the lowest quality peat was collected from Bisika peat bogs. It higher calorific value was 3,060kcal/kg and it was found to contain more ash than volatile matter. However, no fixed carbon was detected in all four samples. The peat is generally the lowest ranked coal with a high moisture content and volatile matter. This might be resulting from the process of the peat formation. Indeed, peat is treated as a subcategory within brown coal and is defined as a combustible soft, porous, or compressed fossil sedimentary deposit of vegetal origin with a high water content (up to 90 percent in the raw state), which is easily cut and light to dark brown in color (Jean de Dieu, 2016).

Results of Peat samples pyrolysis

In proximate (wet) analysis of the data, the naturally dried peat 1contained 10 to 20% of moisture and the peat-2 has more volatile matter and less ash than peat-1 sample. As summarized in the table1 below, the results found after pyrolysis revealed that the peat samples contain higher amounts of volatile matter, at 60-70%, and less fixed carbon than Indonesian high-moisture bituminous coal and Mongolian lignite in a dry condition. Also according to an ultimate analysis, peat contains more oxygen by about 10% as reported that the carbonization of low rank coal at 480^{o} C-600^{o}C, most of the volatile matters are driven off (Perlack et *al*, 1986).

Table1: Results of industrial proximate and calorific value analysis of the Rwanda peat

Peat bogs	Proximate Analysis (as received basis, weight %)				Ultimate Analysis (Dry ash free basis, weight %)					HHV (Kcal/Kg)	LHV (Kcal/Kg)
	M	VM	Ash	FC	C	H	N	O	S		
Bisika	78.41b	10.8	10.64a	0.12	50.1c	50.1c	1.2	41.72a	1.64	2060b	1471.8b
Bahimba	77.53b	10.9	11.51a	0.11	53.2abc	53.2abc	1.2	38.9ab	0.99	2132.2b	1496.9b
Ndongozi	83.84a	12.1	4.01b	0.10	57.1ab	57.08b	1.8	33.7c	1.37	3280a	2533.8a
Nyirabibande	83.67a	11.2	5.12b	0.05	57.5a	57.5a	1.6	34.3bc	0.55	3413.33a	2647.4a
Average	80.86	11.2	7.82	0.09	54.5	54.5	1.5	37.19	1.14	2721.39	2037.5

**the mean with the same letter in the same column are not significantly different; M – Moisture; VM – Volatile matter; FC – Fixed Carbon; C-Carbon; H-Hydrogen; O-Oxygen, S-Total sulfur; HHV-High Heating value; LHV-low heating Value*

On the other hand the results of the gas generated during peat pyrolysis are presented in table2 above. According to the gas composition analysis, both peats showed similar patterns. H_2 Showed a value of approximately 23%, CO 21-24% and CH_4 16-17%. The calorific value of the gas was higher than 3,800kcal/sm$^{3.}$ to evaluated. In comparison with the Indonesian coal (Umar, 2006), although the pyrolysis temperature in the experiment of Indonesian coal was 800^{o}C, it was observed that the calorific value is higher than of Indonesian coal gas. It was revealed that the composition of H_2 or CO was about 7-10% lower, but the proportion of hydrocarbon gas (CH_4) having a high calorific value was higher. Therefore, the calorific value of the peat gas is increased overall (Sorum, 2001).

Lastly, the results found about the recovered char are presented in the table2 above. Compared to the results of the dry proximate analysis of the original peat samples as presented in the table1, the volatile matter of the peat-1 char and peat-2 char samples sharply decreased from 60% and 77% to about 10%, respectively. Whereas the ash content increased to about 37-38% in both peat chars as the volatile matter was decreased. Consequently, peat from Bisika, Bahimba, Ndongozi and Nyirabirande are dried bogs. Dry peat mining methods involve the draining of a peat bog first, to allow it to dry naturally over a certain period of time (Hosier et *al*, 1993, Laird et *al*, 2009).

Table2: Proximate, ultimate and calorific value analysis of Rwanda peat char

Sample	Proximate Analysis (as received basis, weight %)				Ultimate Analysis (dry ash free basis, weight %)					HIV (Kcal/Kg)	LHV (Kcal/Kg)
	M	VM	Ash	FC	C	H	N	O	S		
Rwanda peat char1	0.7	10.5	38	51	55	1	1.7	4	0.6	5170	5110
Rwanda peat char2	0.6	10.9	37	55	55	1	1.6	4.9	0.7	5180	5120
Average	0.65	10.7	38	53	55	1	1.7	4.4	0.65	5175	5115

On the other hand, the fixed carbon increased from 26% to 50% in a case of the peat-1 char, while the fixed carbon increased from 19 to 51% in a case of the peat-2 char. In both peat char, the fixed carbon almost doubled. As result, the ash content increased, but the fixed carbon having a higher calorific value than volatile matter increased greatly. Therefore, the overall calorific value was improved, meaning that the peat classified as the lowest rank of coal, was converted into higher ranked fuel. These peat char results are in the same line with the conclusion, stipulating that A related carbon storage proposal should gained considerable attention at the beginning of the 21st century calls for heating biomass in the absence of oxygen (pyrolysis) and applying the resulting carbonized material to agricultural or forest soils (EUEI,2009; Sohi2010). The solid product of pyrolysis, called "biochar" in the context of climate change mitigation, is highly heterogeneous material with chemical composition that varies widely depending on feedstock and pyrolysis conditions (Spokas, 2010).

Conclusion and recommendation

The present experiment which was carried out over 40 peat samples collected across Rwanda peat bogs namely Bahimba and Bisika in Rulindo District, and Ndongozi and Nyirabibande in Burera District. The main purpose of the experiment was to assess their fuel characteristics in order to utilize them as fuel. After applying The KIER technology for upgrading low-rank coal, it was revealed the rwandan peat can be turned into a higher ranked coal by a column flotation process. Thus, according to energy patterns in Rwanda, peat briquetting or hybrid peat pellet for household/industry is highly recommended. In addition, the combustible gas can be tested for power generation and recovered high-calorie peat char for cement factories.

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