PAPER • **OPEN ACCESS**

Research of natural biomass conversion in the Republic of Burundi

To cite this article: J.A. Manigomba *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **288** 012105

View the article online for updates and enhancements.



IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 39.105.153.125 on 23/09/2019 at 04:20

IOP Conf. Series: Earth and Environmental Science **288** (2019) 012105 doi:10.1088/1755-1315/288/1/012105

Research of natural biomass conversion in the Republic of Burundi

J.A. Manigomba [1], N. D.Chichirova [2], V.B.Gruzdev [2]

[1]Laboratory of Burundian State Scientific and Agrochemical Institute (ISABU), Bujumbura, Burundi.

[2]Kazan State Power Engineering University, 420066, Kazan, Krasnoselskaya, str. 51, KSPEU, Russia

amanigomba@yahoo.fr

Abstract. The paper investigates the solution of an urgent energy problem in Republic of Burundi. The pyrolysis process using a recycling of peat, wood waste, agricultural biomass, domestic and industrial waste with the objective of obtaining a secondary energy resources is proposed. Based on this method a pyrolysis gas with a ratio of CO and H2 varied from 1:1 to 1:3 is obtained. The main variable factors determining this composition are the temperature. With the increase of temperature, the pyrolysis gas increases. The number of experiments with fixed factors was chosen at least eight. The experimental setup was used to study the pyrolysis gas of dry sawdust and peat in the temperature range from 450 to 1150°C.
Key words: Thermal power stations, biomass, electric power deficiency, peat, ecology.

Introduction

The Republic of Burundi is located in the eastern part of Africa with a population of more than eight million people. The main energy source (more than 94%) for the population is wood and peat burned by open fire [1]. There is no hydrocarbon fuel in the Republic of Burundi, therefore the republic is forced to procure oil products in Tanzania, Congo and Kenya to operate its diesel power plants. But a steady rise in oil prices leads to a significant increase in the cost of produced electricity, which negatively affects both the republic economy and its energy security.

Over the past two decades, many researchers have studied the pyrolysis of biomass of various species, ranging from wood, agricultural waste, herbaceous species, subjected to various pyrolysis conditions to produce carbonized, liquid and gaseous products [2-5]. Bajus [2] investigated the pyrolysis of wood sawdust using a batch reactor under various conditions of temperature change. The results showed that wood pyrolysis products can be divided into three groups: 25.1% of the mass of the gas, 44.3% of the mass of the liquids and 30.6% of the solid residues. The main composition of liquid products: acetic acid, furfural acid formand. The main fraction of pyrolysis products of the gas are CO2, CO and CH4. The results of the experiments show that the composition of pyrolysis products strongly depends on the heating conditions [2]. Lazi et al. [3, 4] investigated the pyrolysis of agricultural residues and chips in a radiation furnace at different radiation intensities at temperatures ranging from 650 to 1000 °C. The values of the fraction of each product varied with temperature. If the temperature increased, the fraction of the solid residue initially decreased. Then, at high temperatures, there was a tendency to increase the yield of the carbonized component until a constant

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

value was reached. The gas fraction mainly consisted of CO, CO_2, CH_4 and a small amount of H_2, C_2H_4, and C_2H_6. Gases of intermediate value were obtained from wood, while the products of the highest value came from straw. In [5], the authors studied heat transfer in a biomass layer under slow pyrolysis conditions in conjunction with the process of changing the biomass layer thickness. It was found that the endothermic dewatering process takes place at a temperature in the biomass layer from 200 to 300 °C. At temperatures ranging from 300 to 400 °C, the biomass layer is rapidly compressed due to the formation of resin from cellulose to a volume of one-third of the biomass of the initial volume.

In this paper, pyrolysis gas was obtained by using a recycling peat, wood waste, agricultural biomass, domestic and industrial waste. The studied species of biomass have practically the same elemental composition in C, H2, and O2. The study of the regularities of rice straw and wood, thermo chemical transformations, which were observed during pyrolysis and combustion, was also carried out by thermal analysis in various modes on a derivative of grade Q-1500D and experimental installations in a stationary and moving layer at different heating rates.

The investigation of obtaining pyrolysis products process

In this work, the pyrolysis of agricultural and wood waste widely distributed in Burundi is studied. Therefore, we will consider the vegetable briquettes, which have recently been widely used in small power engineering in Burundi. Briquettes and pallets can be obtained from cereals waste such as rice, sorghum, peas, beans, corn, etc. Table 1 shows the annual production volumes of some agricultural products and their wastes in Burundi [6].

Table1. Volumes of production and waste of some type's agricultural products in the Republic of Burundi

№	Sort	Production, tons / year	Waste, tons / year
1	kidney bean	220218	33065
2	Corn	123000	18450
3	Sorghum	67947	10192
4	Rice	67947	10192
5	Peas	33500	5025

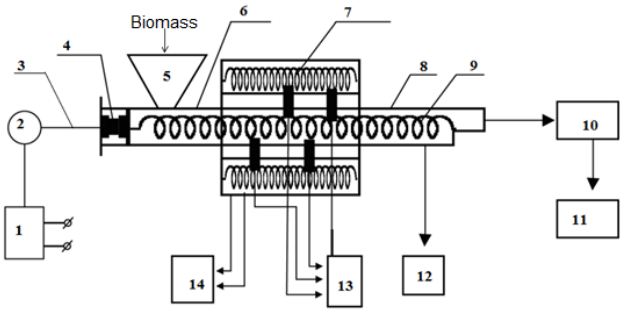

Fig.1. Block diagram of a laboratory unit for the solid biomass pyrolysis of in the moving layer

We investigated the process of pyrolysis of biomass samples in a fixed layer and in a fluidized layer. Studies in the fixed layer were carried out in a quartz glass retort with external electric heating at a heating rate of 6-9 OC / min at temperatures from 450 to 1150 ^{O}C. Pyrolysis of biomass samples in a pseudo-liquefied layer was studied in a laboratory facility consisting of a pyrolizer with a screw feeding of raw materials and external electric heating. The block diagram of the plant is shown in Fig.1.

The main elements of the flowchart are: 1– screw speed controller; 2 - motor-reducer: 3 - drive shaft of a moving screw; 4- seal block with front shaft support; 5 - receiving hopper with hermetic lid; 6- the main part of the screw body; 7- electric heater, power 1,75 kW; 8 - additional removable part of the screw body; 9-moving screw; 10 -filter-cooler of pyrolysis gas; 11-gas meter; 12 - receiving flask of solid residue; 13 - thermometers; 14–electric source of power to heater. The volatile products formed as a vapor-gas mixture in the reaction zone of this plant are discharged to the cooling and purification system 10, then to the gas meter 11, and the solid residue (coke) is collected in the receiving flask 12.

Table 2 presents data on the main components including in the studied samples organic mass. The studied species of biomass have practically the same elemental composition in C, H_2, and O_2. The study of the regularities of rice straw and wood, thermo chemical transformations, which were observed during pyrolysis and combustion, was also carried out by thermal analysis in various modes on a derivative of grade Q-1500D and experimental installations in a stationary and moving layer at different heating rates. The exponents are performed in the laboratory of the Burundian State Scientific and Agrochemical Institute (ISABU), Bujumbura. All experiments were conducted in closed rooms at an air temperature of 24-26°C. Thermocouples with a soldering diameter of 0.2 mm were used to record sample temperatures. The samples were weighted on OHAUS, PA 214C analytical weights. The samples were cooled in a laboratory desiccator. Samples were burned in a Carbolite RHF 1406 furnace at 8 different temperatures, 450, 550, 650, 750, 850,950, 1050, 1150°C. It is known that the difference between the initial weight and weight at a certain temperature, divided by the initial weight, expressed in %, gives the yield of volatile gases from studied the sample. Two methods were used to study the samples for the release of volatile gases.

Table2. The average composition of the resulting pyrolysis gas from solid household waste.

№	Pyrolysis gas composition	Component content, %	Calorific value (bottom), MJ/m3
1	Methane(CH4)	33 – 45	35,80
2	Hydrogen(H2)	12 – 28	10,80
3	Carbon monoxide(CO)	11 – 18	12,64
4	Carbon dioxide (CO2)	1,5 – 2,5	-
		Total	59,24

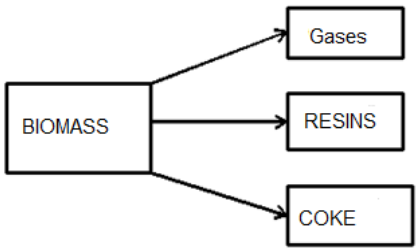

Fig. 2. Single-stage biomass pyrolysis kinetics scheme

1. A method for raw samples, when all samples without drying were placed simultaneously in a cold furnace, were heated to 450°C, held for 5 minutes, the oven furnace was turned off, all samples were taken out of it, cooled in a desiccator, weighted on an analytical balance of OHAUS, PA 214C, then again placed in the furnace, set the desired temperature of 8 values, included the furnace in the work. But since the temperature in the furnace has already decreased, in this case the combustion time could increase, since we detected the minutes 5 times from the time of the furnace reached the desired temperature. The results of the first method for determining the quantity of volatile gases yield at different temperatures, when each sample was tested in two parallel samples, and then separately from other samples, were tabulated.

2. A method for annealed samples, when the dried samples, after their initial humidity determining in the first method, each sample was placed separately from the others in a furnace preliminarily heated to the required temperature, the specimen was held for 5 minutes, the sample was taken out of the furnace, cooled in desiccator and weighted on analytical weights of OHAUS, PA 214C brand. It is known that the composition of the pyrolysis gas mainly includes CO and H_2. But depending on the method for producing pyrolysis gas, the ratio of CO: H_2 varies from 1:1 to 1:3. In direct dependence on the raw materials and the method of its processing, the paper components ratio can vary within wide limits. As a rule, the substances percentage in crude pyrolysis gas is as follows: CO - 11-18%; H_2- 12-28%; CH_4 = 33-45%; CO_2 - 1.5-2.5%. There is average composition of the pyrolysis gas obtained from biomass, and its energy value in table 2.The objective of our study is to maximize the production of pyrolysis gas as fuel from biomass and peat to ensure the operation of diesel generators of the industrial group "REGIDESO" and gas piston machines (GPM). It is known that the yield of pyrolysis gas from biomass depends on its temperature, so in our case the temperature reaction rate dependence will be considered using the Arrhenius equation.

The biomass thermal decomposition can be described on the basis of the simplified kinetic scheme shown in Fig.2 [6-8]. In accordance with this scheme, let us consider the decomposition of biomass in the high temperature region with the formation of final products, such as coke, gases and resins. The formal rate constants of these processes can be represented as the Arrhenius equation:

$$k = k_o A \exp\left(-\frac{E_a}{RT}\right). \quad (1)$$

where k_o is a factor that does not depend on temperature, but is determined only by the type of reaction; E_a is the activation energy that characterizes the minimum energy that the particles must possess in order to enter into chemical interaction, depends on the nature of the reacting substances and independs on their temperature, J /mol; T is the temperature of the biomass, ^{O}K; R is the universal gas constant, equal to 8.31 J / mol * K.

In the calculations, carried out in this paper, the rate constants values for coke, gases and resins reaction formation were calculated on the basis of the empirical expressions presented in [9].

Results discussion

Based on the calculations results and literature analysis [10-13], it can be concluded that the main characteristic of biomass controlled thermal decomposition is a product composition its thermal conversion. Therefore, the target function in the planned experiments was the finite (at a certain point in time, corresponding to the achievement of a fixed temperature) products composition (solid, liquid and gaseous).

The main variable factors determining this composition are the temperature of the sample at the end of a single experiment, the heating rate, the biomass type, and the temperature interval. The choice of temperature changes was carried out by the method of successive approximations when the full conversion conditions were reached. The heating rate values were chosen based on the actual possibilities of the installation for industrial thermal biomass conversion. Temperature changes intervals were chosen on the basis of conditions ensuring maximum reliability of the experimental results. The results of the measurements were tabulated on the basis of which the graphs were plotted in Fig.3, when all samples were simultaneously placed in a cold furnace and heated whether to 450°C.

As the studied raw samples for pyrolysis, there were briquettes from:

Graph 1-series of 8 experiments with briquettes from rice, coffee straw and husk, initial humidity ≈ 6%;

Graph 2 - series of 8 experiments with briquettes from rice straw and wood initial humidity of 6%;

Graph 3 - series of 8 experiments with briquettes from peat A, initial humidity ≈ 6%;

Graph 4 - series of 8 experiments with briquettes from peat B, initial humidity ≈6%.

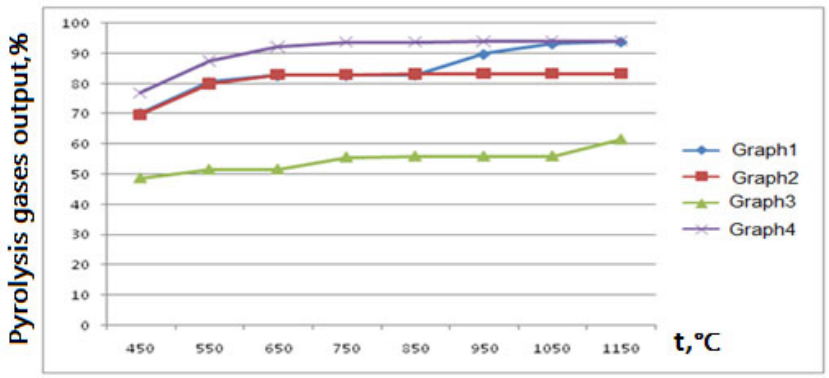

Fig.3 The dependences of the pyrolysis gas share yield from various briquettes from the temperature in the furnace.

The main types of biomass in Burundi - sawdust of Burundi palm, local peat of two deposits A and B, rice and coffee straws and husk were used for research. In preliminary experiments it was found that, despite the high requirements to the stability of the conditions for conducting a single experiment on all significant factors, some scattering of the experimental data took place. For this reason, the number of experiments with fixed factors was chosen at least eight. The experimental setup was used to study the pyrolysis of dry sawdust and peat in the temperature range from 450 to 1150 ^{O}C. It follows from Fig.3 that the total yield of the gaseous phase of pyrolysis in the region of the investigated temperatures depends significantly on the temperature in the furnace and reaches a maximum value when pyrolysis of briquettes from peat B, with a moisture content of not more than 6%. Analysis of the curves in Fig.3 shows that the briquette of rice, coffee straw and husk (series 1) with a significant increase in temperature in the furnace, has a rather sluggish yield of volatile gases, but at a temperature of 1000°C, it begins to rise sharply and reaches its maximum value of about 93%. A further temperature increase in the furnace does not lead to an increase in the volatiles yield from the sample.

A similar intensity volatile gases release is also observed in the series 2, but with a further increase in temperature over 650°C, the value of the volatile gas yield remains at 62%. Hence, it can be concluded that in series 1 with, rice, coffee straw and husks, which have an insignificantly dense structure of plant tissue and with a high air content, first the concentration of volatile gases in the temperature range (550-850°C) is stabilized, and then the stepwise conversion increase with an increase in the volatile gases yield from 82% to 93%, takes place. A series of 3 showed that the distillation of a briquette from peat A leads to a slowed down biomass decomposition reaction of, but with the temperature increase, the volatile yield continues to grow and reaches its maximum at 61% at a furnace temperature of 1150°C. Series 4 showed that the briquette from the local peat B has a more rapid rate of volatile gas evolution, which begins to increase especially from 550 to 750°C, i.e. the volatiles yield in this range was 1% for every 40°C temperature increasing in the reactor. Further temperature increase in the reactor no longer leads to an increase in the volatile gases yield from the sample. Hence it can be concluded that for peat B there is no need for high-temperature conversion and it can be satisfied with the low-temperature pyrolysis process, which is both economically and technically very beneficial for the further application of local peat type B. The obtained pyrolysis gas from type B peat has a real application as a fuel for both gas-diesel and GPM. But in order to bring it to the quality of natural gas, it is necessary to better clean both liquid (distillate) and solid fractions, which will slag the fuel supply chamber in diesel and in GPM. Nevertheless, further deep processing of pyrolysis distillate makes it possible to obtain various commodity fuel products, such as diesel fuel, gasoline, kerosene, fuel oil, solar oil, which are very relevant for the national economy of Burundi.

Conclusion

The conducted experiment of 4 series with 8 temperature measurements to determine the share of volatile gases from briquettes of the main industrial fuels used in the Republic of Burundi showed that it is quite feasible to use local type B peat to produce pyrolysis gas in sufficient volume for successful operation of the industrial group "REGIDESO" diesel -generators and in the GPM.

Fast and high-temperature pyrolysis makes it possible to maximally preserve the energy capacity of rice, coffee straw and husks, as well as wood from Burundi palms, and thereby increase the volatile gases yield for a longer time with high-temperature conversion.

Using the experiment, the important role of the temperature influence on gasification process results, especially on the pyrolysis gas output from local peat species, was determined. A threshold temperature ($450^{O}C$) was also established, at which there is a sharp increase in the gas yield of from the type B peat and, as a consequence, in its volume and calorific value increase.

In general, it was determined that with an increase in the conversion temperature, an improvement in the main parameters of the resulting pyrolysis gas from local biomass species is observed, which is especially important for diesel generators and GPM, with an electricity significant deficit in the Republic of Burundi.

Acknowledgments

This work has been supported and supervised by CHICHIROVA Natalia Dmitrievna - doctor of chemical sciences, professor, director of the Institute of Heat Power Engineering, head of the department "TES". We thereby express our sincere gratitude to her for sharing his pearls of wisdom and hard work with us during the entire work.

References

[1] Z.A. Manigomba, N.D. Chichirova, V.B. Gruzdeyv, “Prospects for the use of the products of pyrolysis in diesel generators of a company «regideso» in the republic of Burundi,” *Energy sector problems*. Vol. 20, No. 2, pp. 33-40, 2018.

[2] M. M. Wright, D. E. Daugaard, J. A. Satrio, & R. C.Brown, ”Techno-economic analysis of biomass fast pyrolysis to transportation fuels,” Fuel, Vol. 89, pp.2-10, 2010.

[3] J. F. González, S. Román, J. M. Encinar & G. Martínez, “Pyrolysis of various biomass residues and char utilization for the production of activated carbons,” *Journal of Analytical and Applied Pyrolysis*, Vol. 85, No.2, pp.134-141, 2009.

[4] R. K. Sharma, J. B. Wooten, V. L. Baliga, X. Lin, W. G. Chan & M. R. Hajaligol, “Characterization of chars from pyrolysis of lignin. *Fuel*, Vol. 83, No. 12, pp. 1469-1482, 2004.

[5] M. P. McHenry, “Agricultural bio-char production, renewable energy generation and farm carbon sequestration in Western Australia: Certainty, uncertainty and risk,” *Agriculture, Ecosystems & Environment*, Vol. 129, No.3, pp. 1-7, 2009.

[6] A. V. Bridgewater, “Biomass fast pyrolysis,” *Thermal science*, Vol. 8, No. 2, pp. 21-50, 2004.

[7] D. Mohan, C. U. Pittman, & P. H. Steele, “Pyrolysis of wood/biomass for bio-oil: a critical review,” *Energy & fuels*, Vol. 20, No.3, pp. 848-889, 2006.

[8] N. Prakash, & T. Karunanithi, “Kinetic modeling in biomass pyrolysis–a review,” *Journal of Applied Sciences Research*, Vol. 4, No.12, pp.1627-1636, 2008.

[9] J. Porteiro, J. L. Míguez, E. Granada, & J. C. Moran, “Mathematical modelling of the combustion of a single wood particle,” *Fuel Processing Technology*, Vol. 87, No. 2, pp. 169-175, 2006.

[10] A. V. Bridgewater, D. Meier, & D. Radlein, “An overview of fast pyrolysis of biomass,” *Organic geochemistry*, Vol. 30, No.12, pp. 1479-1493, 1999.

[11] A. Demirbaş, “Gaseous products from biomass by pyrolysis and gasification: effects of catalyst on hydrogen yield,” *Energy conversion and management*, Vol. 43, No. 7, pp. 897-909, 2002.

[12] R. Srinivasaraghavan, T. E. Wilson, & M. J. Stark, "Pyrolysis of Industrial Wastes. In Proceedings of the 32nd Industrial Waste Conference, Purdue University may No.12, pp. 377-386, 1977.
[13] K. Tiilikkala, L. Fagernäs, & J. Tiilikkala, "History and Use of Wood Pyrolysis Liquids as Biocide and Plant Protection Product History and Use of Wood Pyrolysis Liquids as Biocide and Plant Protection Product," The open agriculture journal, 4(1), 2010