Introduction of biomass gasification for rural electrification in Cameroon

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Abstract. This paper aims at boosting the sustainable use of biomass renewable energy potential in Cameroon to generate electricity especially for its rural communities. In this country, woody biomass resources are primarily used for cooking and heating and we aim to increase its utilization through power generation. For this reason, an experiment using a gasification power generation system which was designed and assembled in Ashikaga University was used. The power generation capacity of this system is 20 kW. It is connected to a gas analyser in order to monitor the generated synthesized gas. The rotary engine which was used in this case was operated at running speed of 2800 rpm under two different woody biomass feedstock methods, which are the close-top and the open-top methods. It was then observed that the close-top operation generated more electric power compared to the open-top operation. During this process, the temperatures at the reduction and oxidation layers were both monitored and higher temperatures were obtained during the close-top operation.

1. Introduction

Energy remains an important aspect in the socio-economic milieu of all countries and Cameroon is not immune from this. Industrialization and economic growth depend largely on the availability of energy sources. As such, the development of the energy sector plays an important role in the attraction of foreign investments and growth strengthening. Worldwide, 80% of all energy used by humans come from fossil fuels [1]. Such immense exploitation could exhaust resources within few decades and impose a real threat to the environment which could mainly be seen through global warming. As such, research on cheap, pollution free and renewable energy resources are being carried out.

Biomass is a potential renewable energy source for developing countries and it contributes to more than 80% of the energy supply in all African countries. Africa and particularly central Africa is the only continent where wood will continue to play a predominant role in the coming decades as a source of domestic energy. It is estimated that 83% of the Cameroonian population depends on woody biomass as an energy source and in rural areas, it is often the only source of energy available [2]. It is important to note that only 54% of the Cameroonian population has access to electricity, with an average of 88% in urban areas versus only 17% in rural areas [3]. On the other hand, this country has the third largest biomass potential in sub-Saharan Africa with about 25 million hectares covering three-quarters of its land [4] and one of the attractive technologies for alternative fuel from biomass is through the gasification process [5], given it is suitable for autonomous electricity generation. The present work is also an attempt, intended to introduce this technology in Cameroon given it is sustainable and could be used to solve the problem of low electrification rate of rural areas and at the same time create more job opportunities within the country.
2. Gasification systems
Gasification is a process for converting carbonaceous materials to a combustible or synthetic gas. In general, gasification involves the reaction of carbon with air, oxygen, steam, carbon dioxide, or a mixture of these gases at 700°C or higher to produce gaseous product that can be used to provide electric power and heat or as a raw material for the synthesis of chemicals, liquid fuels, or other gaseous fuel such as hydrogen [6]. Gasification reactions involve the following equations which include as shown in table 1:

| Item | Equation | Enthalpy change (kJ/mol) |
|------|----------|--------------------------|
| 1    | C+2H₂ → CH₄ | -91.0                   |
| 2    | C+H₂O→CO+H₂ | 135.8                   |
| 3    | C+ CO₂→2CO | 168.8                   |
| 4    | CO+H₂O→H₂+ CO₂ | -34.0               |
| 5    | CO+3H₂→ CH₄+ H₂O | -226.6                |
| 6    | C+ O₂→ CO₂ | -395.0                  |

2.1. Downdraft gasifier
Downdraft gasifiers have been very successful for operating engines because of the low tar content [7]. The furnace of the gasifier which is an essential part has four main layers as illustrated in figure 1. In the gasification furnace used in the experiment, the oxidizing agent, air, is introduced into the furnace from the bottom-center. The feedstock added from the top passes through the drying layer where moisture is being removed and then through the pyrolysis layer where the biomass is converted into char and volatile products. These volatile products undergo oxidation at the next layer and at the reduction layer, the char is finally converted into synthesized gas.

Figure 1. Gasification furnace.

2.2. Coupled engine and generator set
The engine used in our case is a specially modified rotary engine manufactured by Mazda, whereby the volume of the oil reservoir is increased to reduce the negative effects of tar. This engine with specifications as indicated in table 2 below is coupled to a Fuji electric motor with specifications indicated in table 3. The Mazda engine coupled to the Fuji electric generator is represented as shown in figure 2 below.

Table 2. Engine specifications.
### Table 3. Generator specifications.

| Parameter            |Specification          |
|----------------------|-----------------------|
| Rated output         | 20 kw (3600 rpm)      |
| Generator            | 2 pole 3 phases       |
| Generated voltage    | 200 V                 |
| Frequency            | 50 Hz                 |
| Interconnection voltage | Three-phase, three-wire system 200 V |

Figure 2. Mazda rotatory engine and Fuji electric generator set.

3. **Apparatus**

The set-up for this experiment consisted of a direct fired downdraft power gasification system. This is part of a triple hybrid grid-connected power generation system. This was designed and assembled in Ashikaga University. The rotatory engine coupled to a generator uses the produced synthesized gas as fuel. The experimental apparatus is represented as shown in figure 3 below:
3.1. The gas analyser

Connected to this gasification system, is a gas analyser through which the synthesized gas generated is monitored. This gas analyser supplied on special order by Fuji Electric company has the following properties represented in figure 4 and table 4 below:
Figure 4. Gas analyser [9].

Table 4. Specifications gas analyser [10].

| Manufacturer          | Fuji Electric Systems Company Limited |
|-----------------------|----------------------------------------|
| Model                 | GASRACK-Z                               |
| Measurement method    | Non dispersion type infrared absorption method, magnetic (O₂), heat conduction type (H₂) |
| Measurement range     | 0～50% CO₂ 0～10/ 25 % O₂  
                         | 0～25/50% CO 0～5/20% CO₄ (Reference value)  
                         | 0～30% H₂                                   |
| Repeatability         | CO₂, CO, O₂, CH₄ Full scale ±0.5%  
                         | H₂ full scale ± 1.0%                      |
| Drift                 | ± 2.0% of zero full scale / week  
                         | ± 2.0% of span full scale / week          |
| Response speed        | 1 min                                   |
| Measurement value display | LCD digital display (4 digits of effective digit)  
                                   | LCD bar graph display (front of PDA, instructions after correction of H₂ total)  
                                   | * The correction calculations are performed on all H₂ meters by the computing unit. |
| Calibration method    | Manual correction mode                  |
| Sampling method       | Function 2°C dry sampling method        |
| Sample volume         | Role 3 - 6 L/min.                       |
| Wetting material      | SUS, Teflon, PVC, Viton, etc.           |
| Power supply          | 100V AC, ■50Hz □60Hz                    |
| Power consumption     | Approximately 700 VA (outlet 200 VA not included) |
| Purge source          | Analyzer purge by atmospheric suction (pump) (about 2 L/ min.) |

4. Results and analysis
Initially, 34 kg of wood is fed into the furnace and converted into charcoal the day before the experiment and this is shown as represented in figure 5 below. Figure 6 below shows the woody biomass material that was utilized during the power generation process.
Later on, the charcoal in the furnace was lighted and the temperature was monitored until it rose to 600°C. At this point, two operations which include the closed top and the open top were conducted and the following observations made:

4.1. Closed top operation
For the closed-top operation, the lid at the level of the hopper is closed during operations and opened only when additional biomass is to be added. This operation was conducted for one hour, during which 4 kg of feedstock was added every 10 mins. Temperatures at the oxidation and the reduction layers were both recorded. The generator speed was set at 2800 rpm and the variation of output power against temperature is shown in figure 7 and output power against CO, in figure 8 below.
4.2. *Opened top operation*

In the case of this operation, the lid at the level of the hopper is left opened throughout the experiment while biomass is being fed gradually. 40 kg of feedstock was consumed for a period of one hour. The generator rotation speed was also set at 2800 rpm and figures 9 and 10 show the output power variation with respect to temperature and output power variation against CO concentration respectively.

**Figure 8.** Output power variation versus CO%.

**Figure 9.** Output power versus temperature.
5. Conclusion

Two operations were conducted on the gasification power generation system. For the close-top operation, the temperature of the oxidation layer varied from 500 to 700°C while that of the reduction layer was between 500 and 600°C. The average concentration of the generated CO gas was 22.64% for 40 kg of biomass consumed, generating an average power output of 15.4 kWh at 2800 rpm generator rotation speed.

In the case of the open-top operation, the oxidation layer could attain a maximum temperature of 660°C while the reduction layer reached 570°C. With the generator speed set at 2800 rpm too, an average output generated power of 10.6 kWh was obtained for a total consumption of 36 kg of woody biomass material.

Given the power output delivered by both the close-top and the open-top configurations, it is observed that there is higher output, at the same set-up of generator speed, for the close-top configuration. As such, we think that biomass gasification for power generation offers one of the most promising and suitable renewable energy technologies for rural areas in Cameroon. Both for grid-connected and autonomous power generation systems, in the closed top configuration.

References

[1] Chopra S and Jain A A 2007 Review of fixed bed gasification systems for biomass CIGR E-journal, Invited Overview IX, p 1
[2] Eba’a Atyi R, Ngouhou Poufoun J, Mvondo Awono J-P, Ngoungnoure Manjeli A and Sufo Kankeu R 2016 Economic and social importance of fuelwood in Cameroon International Forestry Review
[3] Castalia Advisory Group 2015 Evaluation of Rural Electrification Concessions in sub-Saharan Africa, Detailed Case Study: Cameroon chapter 2 p 3
[4] Dr. Birgit Aurela 2012 Cameroon and Renewable Energy, Country at a Glance p 4
[5] Chawdhury M A and Mahkamov K 2010 Development of a Small Downdraft Gasifier for Developing Countries chapter 1 p 2
[6] Rezaiyan J and Nicholas P C 2005 Gasification Technologies-A Prime for Engineers and Scientists chapter 1 p 5
[7] SERIISP-271-3022, DE88001135, UC Category-254- 1988 Handbook of Biomass Downdraft
Gasifier Engine Systems

[8] Sumitomo Electric Industries Ltd. 2004 *Ashikaga Institute of Technology Biomass Power Generation Equipment Complete Book*

[9] Fuji Electric Systems Co. Ltd. 2007 *Ashikaga Institute of Technology, Completed Gas Analysis Book*

[10] Joaquim P B, Piapdje T M U and Tsutomu D 2017 Appropriate feedstock in wood gasification for rural electrification *Energy Procedia* **138**, p 491