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Development of a Linear Optimization Model for Biogas Generation of Electrical Energy using Pig Dung

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Abstract
Biogas is a renewable energy source produced by the breakdown of organic matter in the absence of oxygen. It can be produced from raw materials such as agricultural wastes, manure, municipal wastes, plant materials, sewage, green wastes or food wastes. However, the production of biogas has not been commercialized and people are still depending on natural gas which is non renewable and depleting fast. This study develops a linear optimization model to optimally control pig dung for full-scale biogas power generation using computer simulation. The biogas digestion processes were simulated and a linear state space model was generated. The linear optimization model was implemented and validated by calculating the volume of digester, the volume of biogas and the daily energy generated by biogas. A linear optimization model with a coefficient term of 0.68 and a constant term of 0.77 was developed. The result showed that after retention time of 23 hours, the value of biogas electrical power output with linear optimization increased by 0.12 kWh which is 1.45% increase after optimization. The results show the applicability of the optimization model potential which can be exploited using optimal control scheme. The model developed forms a basis for optimal control of real full-scale biogas production.
Keywords: Biogas, Computer Simulation, Renewable Energy, Linear Optimization, State State Model, Pig Dung.

I. Introduction

Nowadays, factors such as environmental conditions, global warming and sustainable energy growth prompt scientists to explore possibilities of producing low cost and environmental eco-friendly alternative energy resources [1]. Therefore, using materials such as biogas, which is otherwise considered as a waste for energy production is of a great importance. Biogas is considered to be a renewable resource which is environmental eco-friendly because its production and use cycle is continuous and it generates no net carbon dioxide. In addition to the environmental benefits, the rising price of conventional energy and the growing requirements for waste management of organic materials are further arguments in favour of biogas production [[2], [3], [4]].

Biogas is the product of the digestion of organic materials under anaerobic conditions and is one of the most widely used and familiar form of biomass. Substrates such as manure, sewage sludge, municipal solid waste, biodegradable wastes are transformed into methane and carbon dioxide. The gases methane and carbon monoxide can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel and for heating purpose, such as cooking [[5], [6], [7]].

Biogas is a carbon neutral way of energy supply. The production of biogas is sustainable, renewable, carbon neutral and reduces the dependency of fossil fuels. Often, beneficiaries of biogas energy production are fully energy self sufficient because, they produce the electrical energy they consume [8]. The substrates from plants and animals only emit the carbon dioxide they have accumulated during their life cycle and which they have emitted without the energetic utilization. In addition, electricity produced from biogas generates much less carbon dioxide than conventional energy. 1 kW of electricity produced by biogas prevents 7,000 kg of CO_2 per year [[9], [10]].

Some of the environmental benefits of biogas are [11]:

i. Reducing the emission of methane which is also a green house gas;
ii. Establishing a decentralized energy supply;
iii. Providing high quality fertilizers;
iv. Reducing unpleasant local odours;
v. Strengthening regional economies and creating added value;
vi. Fostering energy independence.

However, the use of animal manure, organic wastes and other types of biogas as energy sources depend to a large extent on availability. Availability and implementation are strictly dependent on environmental and energy policies [[4], [6]]. Co-digestion of animal manure and other types of suitable organic wastes in biogas plants is an integrated process in which the organic waste materials are converted into useful biogas energy [7]. On the background of renewable energy production, the process includes intertwined environmental and agricultural benefits, such as [[8], [10]]:

i. Savings for the farmers;

ii. Improved fertilization efficiency;
iii. Less greenhouse gas emission;
iv. Cheap and environmentally sound waste recycling;
v. Reduced nuisance from odors and flies;

II. Production of Biogas

Biogas can be produced by anaerobic digestion with methanogen or anaerobis organisms by digesting the materials inside a closed system or fermentation of biodegradable materials. This closed system is called an anaerobic digester, bio-digester or a bioreactor. Each bioreactor consists of one or several storage tanks for organic material, a fermentation tank and a final storage tank for fully digested sludge as shown in Figure 1. The fermentation tank has two phases, a gas and a liquid phase where organic material is digested by anaerobic bacteria in a relatively complex bio-chemical process [[2], [4], [7], [10]].

All processes involved in anaerobic digestion make different demands on pH-value and concentration of organic acids and they further rely on the full functionality of the other processes. This sensitive balance between the simultaneously running fermentation processes is difficult to maintain [[1], [9], [11]].

Biogas can be compressed the same way as natural gas and used to power motor vehicles [5]. In Nigeria, biogas is estimated to have the potential to replace around 19% of vehicle fuel. Biogas qualifies for renewable energy subsidies in some parts of the world. It can be cleaned and upgraded to natural gas standards when it becomes bio-methane. As the organic material grows, it is converted and used. The organic material then regrows in a continually repeating cycle [[6], [10], [11]].

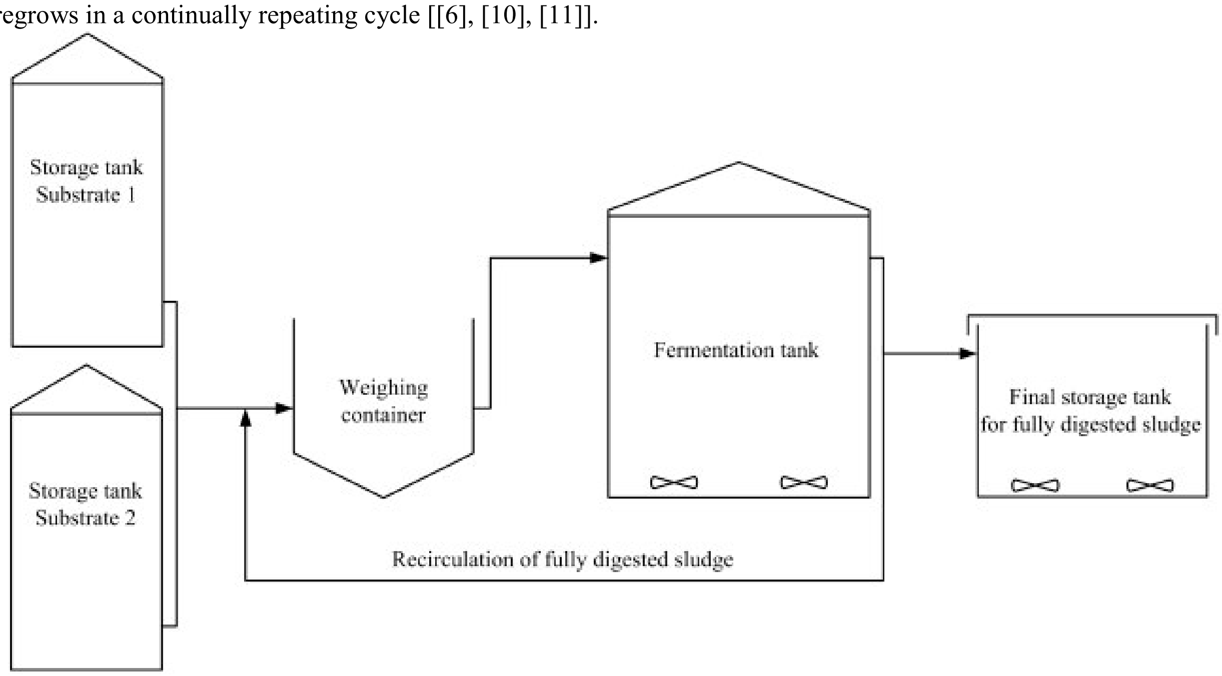

Figure 1: Bioreactor plant of a Biogas.

Biogas optimization process is a major field of research in the area of agricultural and industrial bio technology. Agricultural and industrial activities are the main sources of these solid wastes [9]. Among the agricultural wastes in Oluyole community, pig dung is a major waste available. Pig dung has little dry-matter and organic material content which yields large quantities of methane to produce electricity. It was discovered that it has the best physical and chemical parameters. Therefore, biogas energy production with pig dung can be made more economical to increase the electrical power generation.

III. Materials and Method

This study aims to develop a linear optimization model for biogas electrical power generation using pig dung. A system was designed using computer simulation to simulate, optimize and control full-scale of the biogas plants. In the toolbox, biogas digestion processes (hydrolysis, acidogenesis, acetogenesis and methanogenenesis) are simulated and a linear state space model is generated. The linear optimization model was implemented with the scope of the toolbox, and the daily energy generated for biogas with the standard pigs' dung of unity (1) was obtained using the equation below.

The volume of the digester is given as:

$$V_d = \frac{V_f}{t_r} \qquad 1$$

The volume of biogas is given as:

$$V_b = cm_o \qquad 2$$

The energy generated is given as:

$$E = \eta H_b V_b \qquad 3$$

where; c is the biogas yield per unit dry mass, m_o is the mass of dry input, V_f is the flow rate of digester fluid, t_r is the retention time in the digester and H_b is the heat of combustion per unit volume of biogas.

IV. Discussion of Results

The simulation results are presented according to biogas electrical power output without and with linear optimization.

With a total of 1000 pigs each and a weight of approximately 60 kg used to generate the bio-digester, the values of biogas electrical power output without optimization for 1.5h, 3h, 4.5h, 6h and 7.5h retention time as depicted in Figure 2, are 1.3 kWh, 1.6 kWh, 2.2 kWh, 2.8 kWh and 3.3 kWh respectively. The values of biogas electrical power output without optimization for 9h, 10.5h, 12h, 13.5h and 15h retention time are 3.6 kWh, 4.2 kWh, 4.8 kWh, 5.2 kWh and 5.8 kWh respectively. In addition, the values of biogas electrical power output without optimization for 16.5h, 18h, 19.5h, 21h and 23h retention time are 6.3 kWh, 6.7 kWh, 7.2 kWh, 7.7 kWh and 8.3 kWh respectively.

Figure 3 shows the variation between retention time and biogas electrical power output with optimization. The result shows that the values of biogas electrical power output after optimization for 1.5h, 3h, 4.5h, 6h and 7.5h retention time are 1.33 kWh, 1.67 kWh, 2.28 kWh, 2.87 kWh and 3.39 kWh respectively. The values of biogas electrical power output after optimization for 9h, 10.5h, 12h, 13.5h and 15h retention time are 3.67 kWh, 4.28 kWh, 4.89 kWh, 5.26 kWh and 5.9 kWh respectively. In addition, the values of biogas electrical power output after optimization for 16.5h, 18h, 19.5h, 21h and 23h retention time are 6.39 kWh, 6.78 kWh, 7.28 kWh, 7.79 kWh and 8.42 kWh respectively.

Figure 4 shows the relationship between biogas electrical power output without and with optimization. The values of biogas electrical power output without optimization are 1.3 kWh, 1.6 kWh, 2.2 kWh, 2.8 kWh and 3.3 kWh, corresponding to the values of biogas electrical power output after optimization with values of 1.33 kWh, 1.67 kWh, 2.28 kWh, 2.87 kWh and 3.39 kWh respectively. In addition, the values of biogas electrical power output without optimization are 3.6 kWh, 4.2 kWh, 4.8 kWh, 5.2 kWh and 5.8 kWh, corresponding to the values of biogas electrical power output after optimization with values of 3.67 kWh, 4.28 kWh, 4.89 kWh, 5.26 kWh and 5.9 kWh respectively. The values of biogas electrical power output without optimization are 6.3 kWh, 6.7 kWh, 7.2 kWh, 7.7 kWh and 8.3 kWh, corresponding to the value of biogas electrical power output after optimization with values of 6.39 kWh, 6.78 kWh, 7.28 kWh, 7.79 kWh and 8.42 kWh respectively.

Figure 5 illustrates the comparison between retention time and biogas power output with and without optimization and retention time. The result shows that after retention time of 23 hour, the value of biogas electrical power output increased by 0.12 kWh, which is about 1.45% increase after optimization. The result obtained shows that there is an increase in biogas electrical power output after optimization. From the result, a linear optimization model was generated. The linear optimization model is given as $y = 0.68x + 0.77$

where;

x is the number of pig dung used to produce biogas power.

y is the volume of biogas used to produce biogas power.

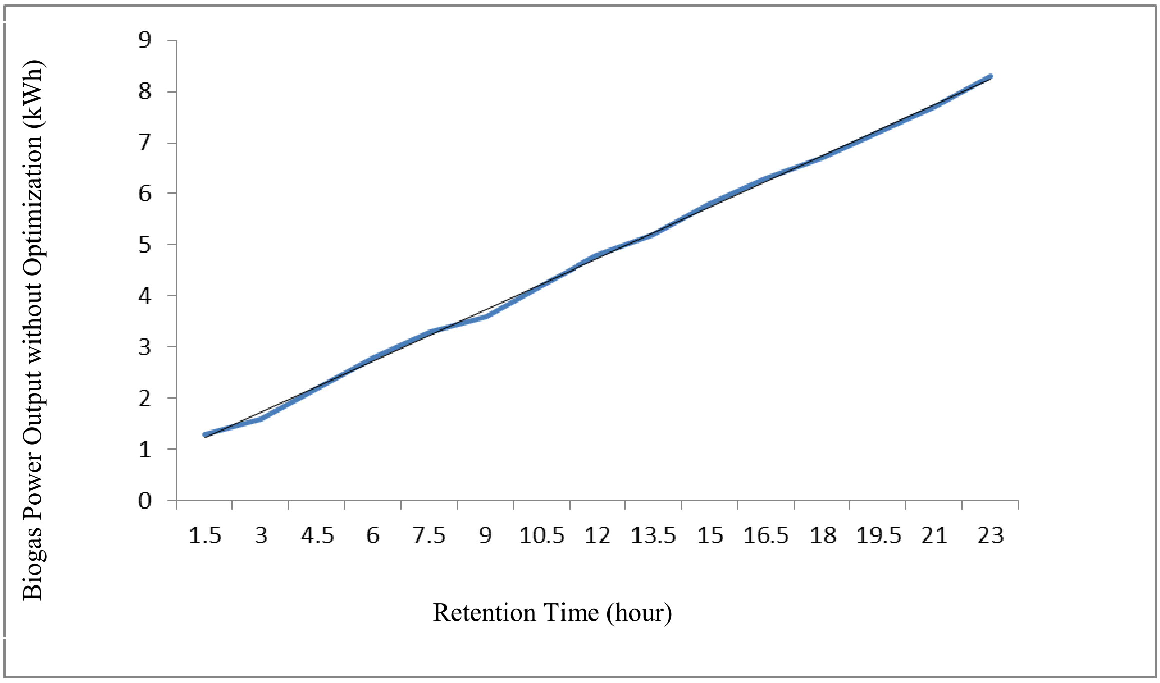

Figure 2: Biogas electrical power output without optimization

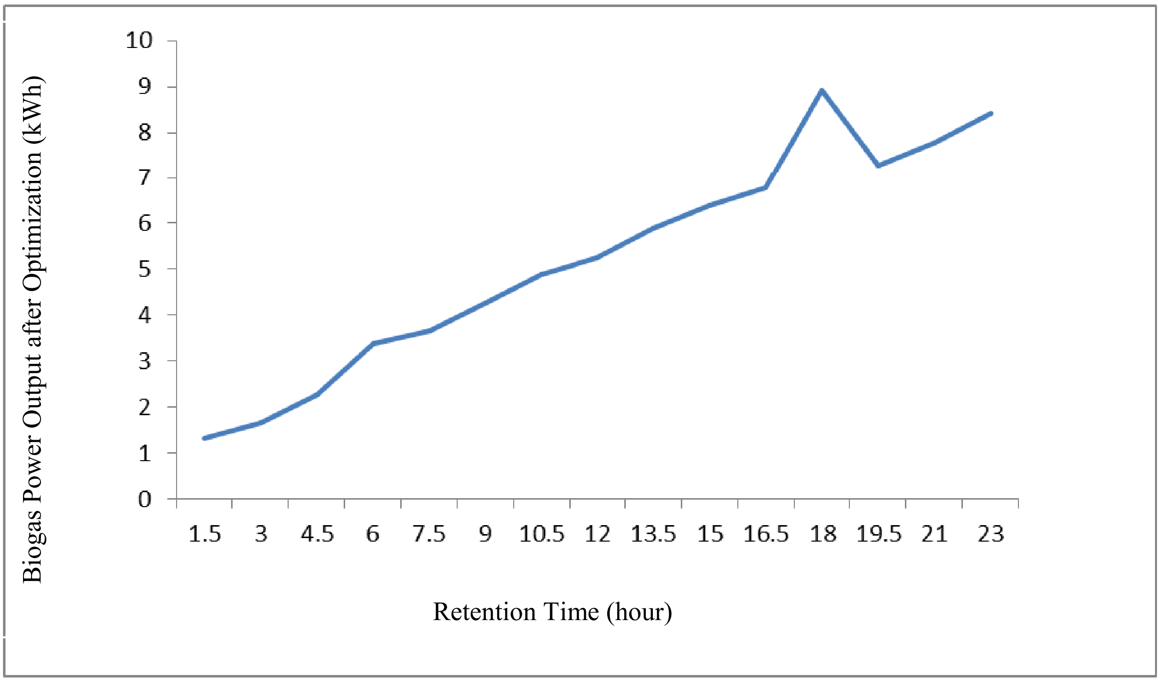

Figure 3: Biogas electrical power output after optimization

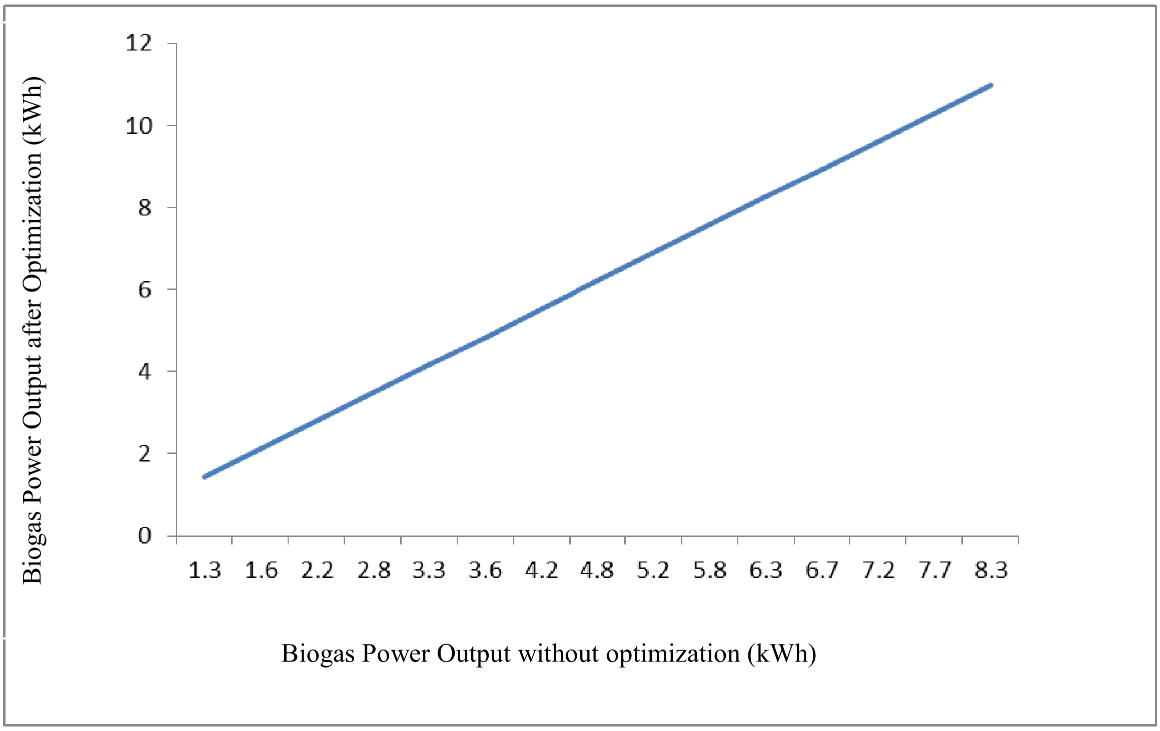

Figure 5: Biogas electrical power output with and without optimization

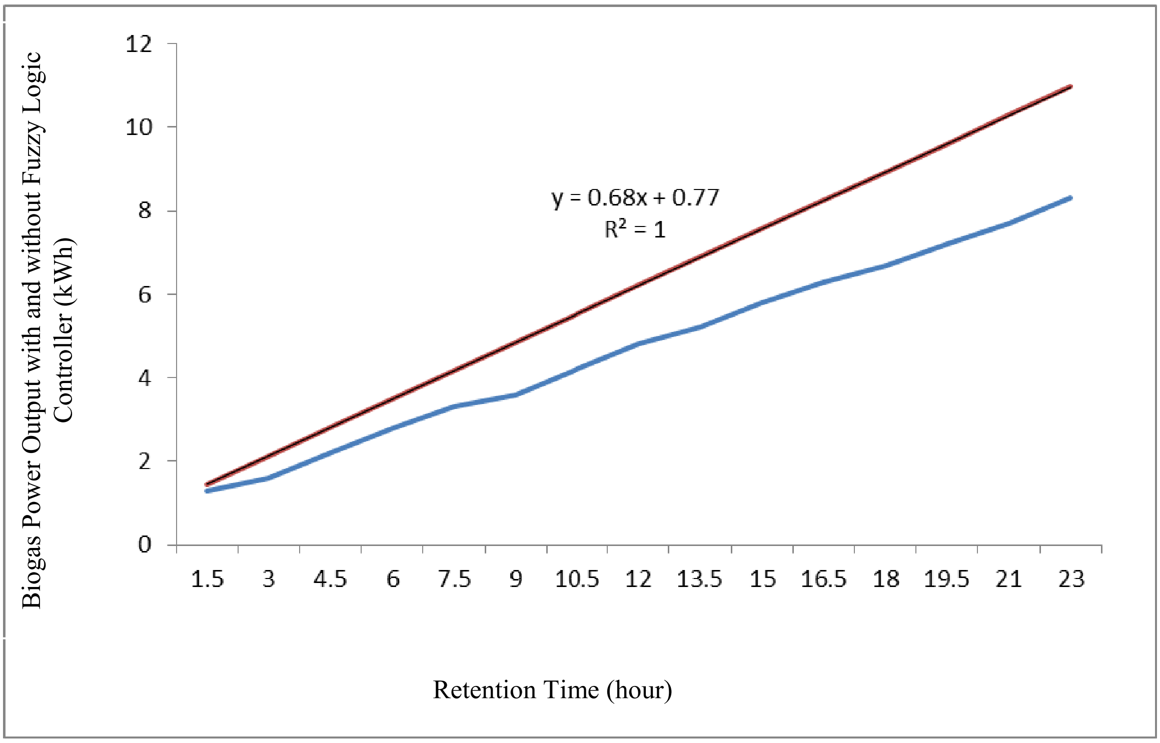

Figure 6: Comparison between biogas electrical power output with and without optimization.

V. Conclusion

In this study a linear optimization model with a coefficient of 0.68 and a constant term of 0.77 was developed using computer simulation to optimally control pig dung for full-scale biogas power generation. The model was generated from the result obtained. The simulation results were presented by comparing the values of biogas electrical power output with and without linear optimization. From the result, it was deduced that there is an increase in biogas electrical power output when the system was optimized. The results show the applicability of the model and the optimization potential which can be exploited using optimal control scheme.

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