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Research Article

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Techno-Economic Analysis of Small-Scale Gas Processing Equipment for Domestic Application

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Abstract Solid wastes are significant contributors to environmental pollution across the world. To satisfy the quest for good sanitation and renewable energy for domestic use in Nigeria there is need for efficient and cost-effective conversion of solid waste into useful energy. The aim of this paper was to carry-out technical and economic analysis of low-cost gas processing equipment which is capable of producing gas from landfill waste materials. A landfill waste processing and treatment unit was designed, fabricated and installed for experimentation. The equipment has three gas production lines designated as A, B & C, each having one vessel of equal capacity of 0.1132 m^3. and fives treatment trains that were designated as 1, 2, 3, 4 & 5 respectively. The total project cost was ₦574,960. An economic analysis carried out using "payback period method" showed that production line "A" with average daily gas production volume of 0.832 Litres/day and payback period of Twenty-Nine months is more economically viable than production lines "B" & "C". Conclusively; landfill gas processing equipment was developed, tested and evaluated economically using locally sourced materials. In addition; quality analysis of experimental gas samples was successfully carried-out. The equipment can be acquired and installed for domestic use by low-income earners across Nigeria with the potential of fulfilling local energy needs of rural community dwellers.

Keywords Payback period, cost-effective, treatment trains, designed, fabricated, installed and experimentation

1. Introduction

According to [1], the origin of waste resulting from human activities dates back to prehistoric times, when waste materials were considered as items with low value or useless commodity. As at that time, waste generation did not pose much threat to human existence, due to small world's population and vast area of land that was available for safe waste disposal.

The challenges of waste management in most developing and third world countries, have continue to increase in due to geometric population growth, industrialization, urbanization and globalization, [7]. In effort to accelerate the pace of its industrial development; an economically developing nation may fail to pay adequate attention to solid waste management [6]. Most developing countries like Nigeria spend huge amounts of money on waste management aspects without commensurate improvements in the quality of services to citizens. This trend is caused by the continuous increase in the volume/quantity of generated municipal Waste (MSW), which is a major consequence of urban lifestyle [8].

Landfilling is one of the most commonly adopted technologies for municipal solid waste (MSW) disposal as an alternative to waste burning and composting. The sanitary landfill method continues to be widely used in different countries for the final disposal of solid waste material due to its economic advantages.

As the name implies, renewable resources are the natural assets that can be replenished in very short period of time. These sources of energy are referred to as alternative sources of energy that are available to mankind through nature, which may require some form of conversion or storage before use for the benefit of humanity, [5].

The poor waste management culture in Africa has negative consequences for the disposal of uncollected waste in dumps as well as the associated severe environmental and health related problems. An integrated approach to solid waste management is required in order to enable local and national authorities to reduce the overall amount of waste generated and to recover valuable materials for recycling and generation of energy, [6].

Raw biogas which is capable of being processed into bio-methane may be produced by a variety of processes that convert organic waste streams into useful energy, [3]. Key sources of bio-methane include: landfills, municipal and industrial waste water treatment plants (WWTPs), and anaerobic digesters using agricultural/farm waste, food processing residue and municipal solid wastes, [4]. Bio-methane for transportation fuel can also be an end product of thermal gasification of more fibrous or woody waste by-products using advance technology.

The process of upgrading and treatment of raw landfill gas can be done by passing the gas sample through several filters. One of the factors that may affect the filtration process is the filter substrates which are classified into two broad categories: surface (or cake) filters and deep-bed filters. Surface filters, as the name suggests, retain the filtered particles on the upstream face of the filter while the depth filters retain the filtrates in the entire matrix of the filter. Surface filters are examples of membrane filters which operate by sieving the particles due to their relatively small pore sizes, [2].

2. Objectives

The aim of this study is to undertake technical and economic analysis of a small-scale landfill gas processing equipment.

3. Materials and Equipment Used

i. Landfill Gas Processing equipment/unit.
ii. Microsoft Excel (2010 Edition).
iii. Laptop
iv. Field notebook
v. Scientific calculator
vi. Gas flow meter
vii. Pen

4. Methodology

The methodology applied for this research involves the following four steps:

Step 1: Gas production

i. Gas production line "A" vessel was charged with 200Kg of partially decomposed bio-degradable landfill waste mixed with, 20 kg of yam peelings, 20kg of plantain peelings and 20kg of dungs from cow as additive in the process. All the components were properly mixed using spade to turn the materials so as to further ensure homogeneity of materials inside the vessel.
ii. Gas production line "B" vessel was charged with 200 Kg of partially decomposed bio-degradable landfill waste mixed with 20kg of yam peelings, 20kg of plantain peelings and 20kg of poultry droppings as additive. All the components were properly mixed using spade to turn the materials so as to further ensure homogeneity inside the vessel.
iii. Gas production line "C" vessel was charged with 200 Kg of partially decomposed bio-degradable landfill waste mixed with 20 kg of yam peelings, 20kg of plantain peelings and 20kg of piggery faecal discharge as additive. All the components were properly mixed using spade to turn the materials so as to further ensure homogeneity inside the vessel.

The three vessels were covered and allowed for fifty-six days to ensure decomposition of waste material into gas.

Step 2: The engineering bill of measurement and evaluation (BEME) was done to calculate the total expenditure on materials for fabrication, labour, consumables and laboratory analysis of produced gas samples using the equipment under test. Details of BEME are presented in Tables; 1, 2, 3 & 4 respectively. The data obtained was then applied to carry-out required (Technical and economic) analysis.

Step 3: Gas collection and measurement

After fifty-six days; gases produced from the lines were collected separately, measured using gas flow meter and figures obtained were recorded in table 5.

Step 4: Data collection and Analysis

Data analysis was carried out using appropriate equations stated below in sections; 5.0, 5.1, 5.2 & 5.3 and Microsoft excel.

Table 1: Engineering Bill of Measurement and Evaluation for labour designated as "BEMEL"

S/N	Items	Qty	Unit price (₦)	Price (₦)
1	Costing of folding plate into cylindrical shape	3 pcs	3,000	9,000
2	Tread tape	12 pcs	300	3,600
3	Spraying/painting of test Rig	-	-	15,000
4	Labour cost for welders	4-man days	5000 per man day	20,000
5	Miscellaneous	-	-	15,000
	Total BEMEL			**62,600**

Table 2: Engineering Bill of Measurement and Evaluation for construction materials, designated as "BEMECM"

S/N	Items	Qty	Unit price (₦)	Price (₦)
1	4mm thick stainless-steel plate	3 full length	25,000	75,000
2	6-inch steel pipe	1 full length	20,000	20,000
3	¾ pipe galvanized steel pipe	2 full length	2,750	5,500
4	½ galvanized steel pipe	1 full length	4,200	4,200
5	3/4-inch ball valve	10 pcs	950	9,500
6	½ inch ball valve	5 pcs	750	3,750
7	Washer	200 pcs	10	2,000
8	¾ union	12 pcs	650	7,800
9	½ union	8 pcs	480	3,840
10	1½ inch pipe	1 foot	670	670
11	Bolt and nuts	96 pcs	100	9,600
12	6" Gasket	12	1,000	12,000
13	Temperature gage	3 pcs	10,000	30,000
14	Pressure gage	3 pcs	10,000	30,000
15	Electrode	3 packets	3,000	6,000
16	Hack saw blade	10 pcs	150	1,500
17	Cutting disk	5	500	2,500
18	Miscellaneous + Transportation	-	-	10,000
	Total BEMECM			**233,860**

Table 3: Engineering Bill of Measurement and Evaluation for Sample collection & Analysis (BEMESCA)

S/N	Items	Qty	Unit price (₦)	Price (₦)
1	Renting of gas bottles	15	1,000 per bottle for 2 days	30,000
2	Cost laboratory analysis of gas samples	15	20,000	200,000
	Total BEMESCA			**230,000**

Note: prices of materials as December 2022

Table 4: Engineering Bill of Measurement and Evaluation of materials for Gas Production designated as "BEMEMGP"

S/N	Items	Qty	Unit price (₦)	Price (₦)
1	Piggery waste	25 kg	20	500
2	Poultry waste	25 kg	20	500
3	Cow dugs	25 kg	20	500
4	Solid waste material	20 bags (1 ton)	250	5,000
5	Silica gel	2 kg	1,000	2,000
6	Calcium oxide	2 kg	1,500	3,000
7	Metalic filter	5 pcs	2,000	10,000
8	Bio filter	5 pcs	2,000	10,000
9	Synthetic filter	5 pcs	2,000	10,000
10	Transportation	-	-	7,000
	Total BEMEGP			**48,500**

Table 5: Gas production line volumes

Total gas production for "A" (litres)	Total gas production for "B" (litres)	Total gas production for "C" (litres)
5.182	3.239	3.793

5. Economic Analysis

The cost data given in section 4.0 (Tables; 1, 2, 3& 4) are required to carry-out economic analysis of the landfill gas processing equipment using "payback period method" as follows;

The following key points and definitions of parameters used in the analysis are noteworthy:

- ✓ The fabricated equipment is made of three separate gas production lines designated as; A, B & C production lines (series sample) respectively.
- ✓ The fabricated equipment has a treatment unit that is made up of five trains designated as; 1, 2, 3, 4 & 5
- ✓ The equipment is designed to provide a minimum service life of ten years
- ✓ TIOP → The total investment on project
- ✓ TIPPL→ The total investment per production line
- ✓ The total expenditure on construction materials (BEMECM) = ₦ 233,860 (from Table 2)
- ✓ The total expenditure on labor (BEMEL) = ₦ 62,600 (from Table 1)
- ✓ The total expenditure on materials for gas Production (BEMEMGP) = ₦ 48,500 (from Table 4).
- ✓ The total expenditure on Sample collection & analysis (BEMESCA) = ₦ 230,000 (from Table 3).

The total investment on project (TIOP) = BEMECM + BEMEL + BEMEMGP + BEMESCA = ₦ 233,860 + ₦62,600 + 48,500 + 230,000 = ₦ 574,960 (5.1)

Hence; the cost per production line is calculated by applying equation 5.2 as follows;

$$\text{TIPPL} = \frac{\text{The total investment on project (TIOP)}}{3} \quad (5.2)$$

$$\frac{574{,}960}{3} = 191{,}653$$

Therefore; the cost per production line = ₦ 191,653.

5.1 Economic Analysis of production line "A"

Payback period method will now be applied to determine the economic analysis of production line "A" using equation 5.3 as follow;

$$\text{PP for "A"} = \frac{\text{cost of project/ investment}}{\text{Annual cash flow from project}} \quad (5.3)$$

Where; PP → payback Period for production line "A" in years.
cost of project/investment per production line = ₦191,653 (determined using eqn. 5.2 above)
Annual cash flow from production line "A" = ₦78,475 per year (₦215 per day) determined.
Hence, putting all parameters in equation 5.3 and solving same we have;
Payback period for production line "A" = $\frac{235,320}{78,475}$ = 2½ years (29 months).

The result of economic feasibility analysis of production line "A" shows that it will take about 2½ years (29 months) to recover the capital put into the project.

5.2 Economic Analysis of production line "B"

Similarly; Payback period method will be applied to undertake economic analysis of production line "B" by putting all required parameters into equation 5.3 and solving same as follows;

$$\text{PP for "B"} = \frac{\text{cost of project/ investment}}{\text{Annual cash flow from project}}$$

Where; PP → payback Period for "B" in years
Remember that; cost of project/investment per production line = ₦ 191,653 (determined using eqn. 5.2 above).
Annual cash flow from project production line "B" = ₦36,500 per year (₦100 per day) determined.

Hence; payback for production line "B" = $\frac{191,653}{36,500}$ = 5¼ years (63 months)

The result of economic feasibility analysis of production line "B" shows that it will take about 5¼ years (63 months) to recover the capital.

5.3 Economic Feasibility Analysis of production line "C"

Also; Payback period method will be applied to undertake economic analysis of production line "C" using equation 5.3 as follow;

$$\text{PP for "C"} = \frac{\text{cost of project/ investment}}{\text{Annual cash flow from project}}$$

Where; PP → payback Period for "C" in years
Remember that; cost of project/investment per production line = ₦191,653 (determined using eqn. 5.2 above).
Annual cash flow from project production line "C" = ₦63,875 per year (₦175 per day) determined.

Hence; pay back for production line "C" = $\frac{191,653}{63,875}$ = 3 years (36 moths)

The result of economic feasibility analysis of production line "C" shows that it will take 3 years (36) to recover the capital.

6. Discussion

The result of economic feasibility analysis of production line "A" shows that it will take about 2½ years (29 months) for the investor to fully recover the capital put into the project. Similarly, production line "B" will take about 5¼ years for the investor to fully recover the capital investment. While production line "C" will take about 3 years (36) for the investor to recover capital investment.
Results also show that; gas production line "A", produced total of 5.182 litres and will generate estimated annual return of ₦78,475. Line "B" had total of 3.239 litres and will generate, annual returns of about ₦36,500.

While gas production line “C” which gave total of 3.793 litres and will generate an estimated annual returns of ₦ 63,875.

7. Conclusion

The rule of thumb guiding business feasibility using payback period method is that; businesses with payback period 3 years and below are accepted as been viable, most investors will be willing to invest their resources into such business ventures. This is because these investments can recover money spent on them within a reasonable length of time for its financiers (investor). From economic stand point, productions line “A” is the most viable, followed by production line “C”, while the least economically attractive is production line “B”.

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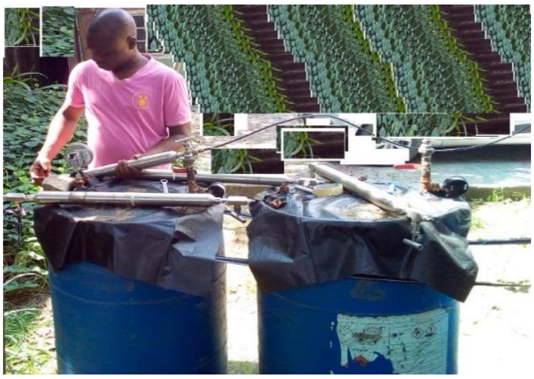
Photos of Test rigs



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