Sewage Sludge Valorisation to Biochar Through Carbonization as a Way of Promoting a Circular Economy in Municipal Sewage Plants

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Abstract

This study focused on the potential to produce biochar from sewage sludge as a waste valorisation initiative. A process for the production of biochar from waste sewage sludge is proposed. Sewage sludge carbonization was done at 300-500 ◦C and retention times of 1-2 hours. Biochar yields of up to 58% were achieved and the biochar had a surface area of 240 mg/g. Initial cost evaluations indicated that for the plant producing 2.8 tons of activated biochar, a rate of return of 41.2% and payback period of 4.3 years.

Keywords
Biochar, carbonization, economic assessment, sewage sludge and site selection and layout.

1. Introduction
The increase in the production of sewage sludge from wastewater treatment plants is causing concern due to possible risks to the environment (Ahmad et al., 2012). Primary sludge contains settle able solids removed during primary treatment in primary and secondary clarifiers. The sludge usually is in the form of a semi-solid containing 24-26%. wt. depending on the treatment operations.

2. Sewage Sludge Valorisation
The excess sewage sludge produced during the biological treatment of municipal wastewater requires expensive disposal procedures including advanced treatment: the cost of sludge disposal accounts up to 50% of the overall cost of wastewater treatment (Bridgewater, 2011). In addition, due to the potentially high metal content, uncontrolled sewage sludge disposal may induce soil and groundwater pollution.

2.1 Sewage sludge characteristics and treatment
Sewage sludge comprises of organic and inorganic substances as well as water (Capodaglio et al. 2016). The first step in sewage processing is sludge thickening to form lager particles (Chia et al. 2015). The initial sewage sludge

is thickened from 8-10%. wt. solids to 14%. wt. solids during the second stage thickening. The water content in the sewage sludge is further reduced through centrifugation, evaporation and filtration (Ding et al. 2017).

2.2 Biochar characteristics and production materials

Biochar is a black carbon material derived from thermal degradation of carbon-rich biomass in an oxygen-limited environment. Biochar has multi-functional uses including carbon sequestration, soil fertility enhancement, bio-energy production, water and wastewater treatment as well as environmental remediation (Hai et al. 2018). Biochar is produced from various feedstock materials including agricultural and forest residues, industrial by-products and wastes as well as municipal solid waste materials (Jeong et al. 2016). Biochar can also be produced from industrial wastes and by-products (Powar and Gangil. 2015). Non-conventional materials such as waste tires, municipal solid waste, newspapers scraps, plastics and food wastes are also raw materials for producing biochar (Wang et al. 2010).

2.3 Biochar uses

Biochar can be used in water and wastewater treatment for sorption of heavy metals and organic pollutants (Bridgewater, 2011, Capodaglio et al., 2016. The physicochemical properties of biochar such as surface area, charged surface and functional group vary based on the biomass source and pyrolysis condition, which affect the adsorptive capacity of biochar to heavy metals and organic compounds (Ahmad et al., 2012).

2.4 Preparation of biochar

Biochar physical and chemical properties are based on the technology used either: pyrolysis, gasification, hydrothermal carbonization or flash carbonization. The pyrolysis technology is differentiated by the residence time, pyrolysis temperature, pressure, size of material and the heating rate. Slow pyrolysis is a continuous process where oxygen-free feedstock biomass is transferred into an external heated furnace (Chia et al., 2015). On the other hand, fast pyrolysis depends on very quick heat transfer of less than 650 °C with fast heating rates of 100–1000 °C/s.

In the gasification process, the biomass feedstock is oxidized in the gasification chamber at a temperature of around 800 °C at atmospheric or elevated pressure (Ding et al., 2017). The main product of this process is gas, biochar and liquids. The hydrothermal carbonization of biomass is achieved by applying high temperatures of 200–250 °C to a biomass in a suspension with liquid under high atmospheric pressure for some hours (Hai et al., 2018). Hydrothermal carbonization yields biochar, liquid and gaseous products. biomass liquid suspension. In flash carbonization, a flash fire lights up at a high pressure of 1–3 MPa at the underneath of a packed bed biomass. The fire travels in an upward direction through the carbonization bed against the downward flow of air supplied to the process. A total of 0.8–1.5 kg of air per kg of biomass is injected to the process. The residence time of the process is below 30 minutes and the temperature in the reactor is in the range of 330–650 °C.

3. Results and Analyses

3.1 Raw sewage sludge characteristics

The sewage sludge was obtained from the Chitungwiza sewage plant in Zimbabwe and was characterized for its composition on a wet basis. The sewage sludge was mainly composed of 89.2 %wt. slurry, primary screenings of 6.4 %wt. and grit of 4.4 %. wt. The summary of the sewage sludge characteristics is given in Figure 1. The sewage sludge composition made it ideal for conversion to biochar.

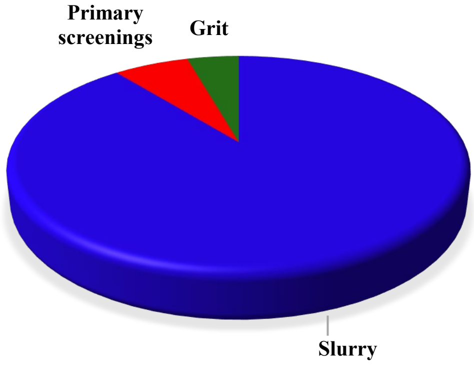

Figure 1. Sewage sludge composition

3.2 Effect of varying time and temperature on biochar yield

The sewage sludge was converted into biochar at temperatures ranging from 300-500 ◦C at retention times of 1-2 hours in a lab furnace. The biochar yield was calculated through the difference between its mass before and after carbonization. The biochar yield was calculated in accordance to Equation 1 after a 500g sample was used for the yield determination. The biochar yield decreased with increase in carbonization temperature from 300 ◦C to 450 ◦C. In addition, the biochar yield decreased with increase in reaction time in the furnace (Figure 2). A highest biochar yield of 58.4% was observed at carbonization temperatures of 300 ◦C and a reaction time of 1 hour. Zhengwen et al. (2011) observed the same trend for carbonisation temperatures of 400-800 ◦C for biomass pyrolysis in a fixed bed reactor.

$$Biochar\ yield\ (\%) = \frac{Weight\ of\ biochar}{Weight\ of\ feedstock}\ x\ 100 \ldots\ldots\ldots\ldots\ldots (1)$$

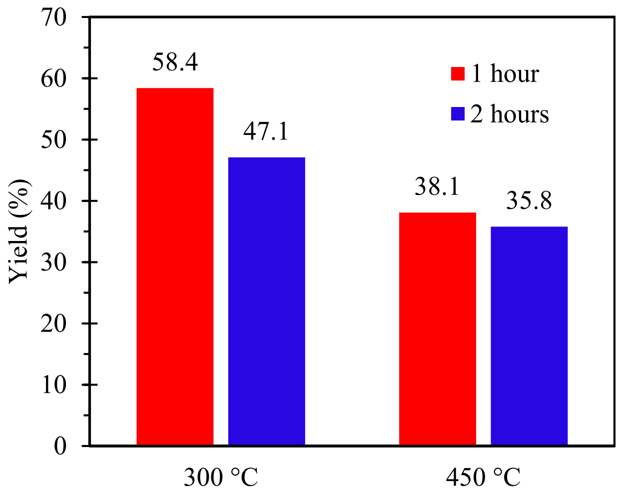

Figure 2. Effect of retention time and carbonization temperature on biochar yield

3.3 Effect of moisture content

Biochar must have as minimum moisture content as possible for easy storage and transportation (Figure 3). The biochar moisture content was reduced from 13.6% to 4.4% during drying. The moisture content was calculated in accordance to Equation 2.

$$\text{Moisture content}(\%) = \frac{\text{Initial weight} - \text{Final sample weight}}{\text{Initial weight of sample}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

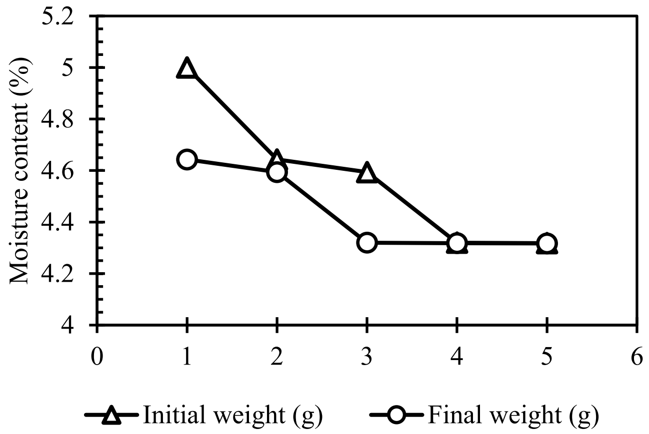

Figure 3. Effect of drying on moisture content

3.4 Biochar iodine number

The iodine number of the sewage sludge biochar was determined according to the Japanese Industrial Standard (JIS) test method (K1474:2014) (Jeong et al., 2016). The results indicated that the experimental biochar possesses a large internal surface area of 240 mg/g. This iodine number for this biochar is ideal for use of the biochar in wastewater treatment as it's a high surface area for adsorption (Anawar et al., 2015).

4. Process Design

The process design covers the process description for the process of producing biochar from sewage sludge. It also includes block flow diagram, material and energy balances for each unit and for the entire process and process flow diagram showing all major equipment and stream compositions. A summary of the biochar production from sewage sludge process diagram is shown in Figure 4.

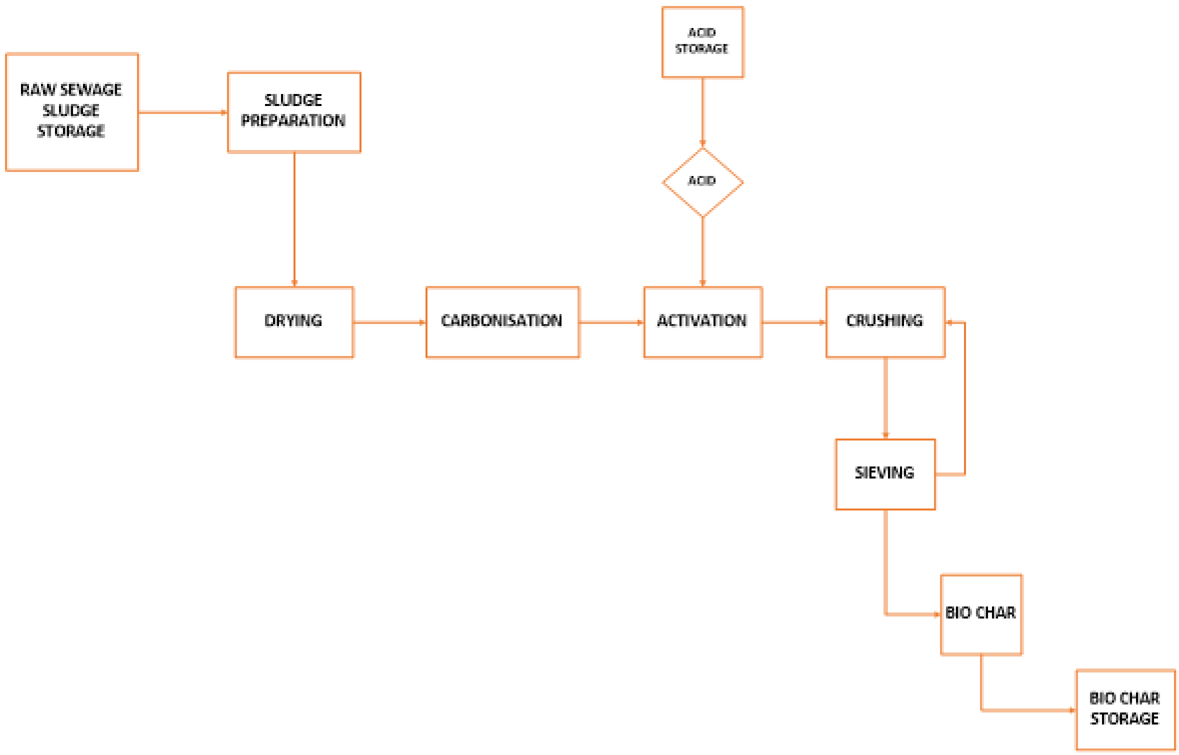

Figure 4. Block flow diagram for biochar production from sewage sludge

4.1 Process description

Biochar was produced by acid activation at the use of elevated temperature. Acid activation is often the preferred method due to its shorter production time and lower temperatures required.

4.1.1 Sewage sludge storage, screening and drying

The sewage sludge is fed from raw sewage wastewater treatment and is stored in storage tanks. Large solid particles are removed by screens consisting of metal bars spaced at 19 mm intervals which are placed across the inlet channels. The process of the sewage sludge drying is done to remove excess moisture. After screening the sludge is transferred into a rotary dryer and dried for 4 hours at 110 ^{0}C.

4.1.2 Sewage sludge carbonization

The process of carbonization is done by tightly packing the dried sludge into a closed pyrolysis reactor to ensure a limited oxygen supply. The carbonization reactor operates at a maximum temperature of 500 ^{0}C and the reaction is 1-2 hours. The gases from carbonization are used to ignite coal that heats the reactor in order to save energy. Most of the non-carbon elements are first removed in a gaseous form.

4.1.3 Biochar acid activation

The biochar is then activated using sulphuric acid. The biochar is then transferred into a mixing tank with heat supply. Using a ratio of 1:1; aliquot of concentrated (98%) sulphuric acid is added and the mixture is stirred for about an hour at 80 ^{0}C. It stirred at 1400 rpm for an hour at 10 minute intervals.

4.1.4 Biochar drying, crushing, sieving and storage

A stainless steel dryer is used to remove excess moisture from the biochar. The drier is fed with slurry from the activation unit and is operated for about an hour at 110 ^{0}C. The dried biochar is crushed and milled for size reduction to <1.5 mm to increase the biochar surface area for reaction. After crushing, the crushed biochar is passed through a series of sieves to obtain particles of the same that is a size of <1.5 mm. Particles greater than 1.5 mm are recycled back into the process for further crushing to reduce their particle size and increase the surface area.

4.2 Material balances

The objectives of carrying out material balances are to come up with a basis for calculation of the plant equipment design parameters as well as for economic valuations. The balances determined the quantities of feed and the composition of each of the streams. The material balance for the process was carried out by applying the law of conservation mass. The general conservation of mass equation for any of the process streams as indicated in Equation 3.

$$Mass\ out - Mass\ in + Generation - Consumption = Accumulation \ldots\ldots\ldots\ldots (3)$$

4.2.1 Overall mass balance and scale-up factor

The assumptions made were: 365 working days per year with 24 hours in a day, batch process, 1m^3 is equal to 1000L and equal to 1000kg and that mass in equals mass out. The scale-up factor was determined for a basis of 9600 kg/day sewage sludge feed and from the experiments: 0.250kg results in 9600 kg/day. Therefore, the sewage sludge required per day is 38 400/day. Amount of sewage sludge (feed) required is equal to mass of sewage sludge from experiment multiplied by the scale up factor which equals to 0.250 kg multiplied by 38 400/day which is equal to 9600kg/day. The amount of biochar produced is equal to mass of biochar from experiment multiplied by the scale up factor which is equal to 0.078 kg multiplied by 38400/day which is equals 2899.2 kg/day. Assuming a lowest 30% yield of the biochar, the plant capacity for producing biochar will be 2800kg/day.

4.2.2 Mass balance on the bar screen

The overall mass balance on the bar screen is shown in Equation 4 and 5.

$$\frac{9600kg}{day} = \left(0.108 \times \frac{9600kg}{day}\right) + x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Wet\ sludge \approx \frac{8626.56kg}{day} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

4.2.3 Mass balance on the rotary drier

The overall mass balance on the rotary drier is shown in Table 1.

Table 1. Mass balance on the rotary drier

Components	Mass in (kg/day)	Mass out (kg/day)
Wet slurry	8600	-
Dried sludge	-	7482
Water vapor	-	1118
Total	8600	8600

4.2.4 Mass balance on the pyrolysis reactor

The overall mass balance on the carbonisation reactor is shown in Table 2.

Table 2. Mass balance over the pyrolysis reactor

Component	Mass in (kg/day)	Mass out (kg/day)
Dried sewage sludge	7482	-
Biochar	-	2244.6
Gases	-	5237.4
Total	7482	7482

4.2.5 Mass balance on the biochar activation unit

The summary of the mass balance on the activation unit is shown in Table 3.

Table 3. Mass balance over the biochar activation unit

Components	Mass in (kg/day)	Mass out (kg/day)
Biochar	2244.6	-
Acid $_{(1.84 kg/L)}$	1472	-
Biochar slurry	-	3532.1
Gases	-	184.5
Total	3716.6	3716.6

4.2.6 Mass balance on the crusher

The overall mass balance on the crusher is assumed that the mass of the dried biochar is equal to the mass of the crushed biochar and the recycle stream. The overall mass balance on the crusher is represented by Equation 6. Assuming the sieve is 100% efficient, the mass in equals the mass out which is 2733.37 kg/day.

$$3106.10\frac{kg}{day} = 0.12\ \times\frac{3106.10\ kg}{day} + Crushed\ biochar = 2733.37\ kg/day \ldots\ldots (6)$$

Assuming the sieve is 100% efficient, the mass in equals the mass out which is 2733.37 kg/day.

4.3 Energy balances

The energy balances were carried out on the process to select the appropriate material for fabricating the equipment in which energy changes occur thus the selected material should have a thermal conductivity that accommodate the energy changes occurring in them and to design a system to harness the energy generated.

4.3.1 Energy balance for the rotary dryer

The drying process is carried out in a direct contact core current rotary dryer. Samples of inlet and outlet bio solids moisture content were taken before and after drying respectively and the optimum temperature was 110 ºC. The thermal properties of the rotary drier were as follows: Temperature $_{inlet}$ is 25 ºC = 298K, temperature $_{within\ the\ dryer}$ is 110 ºC = 383K, temperature $_{outlet}$ is 110 ºC = 383K, specific heat capacity of vapour is 4184 J/kg/K and specific heat capacity of sludge is 17.97 MJ/kgK.

Inlet stream

$$\mathrm{Qin} = \mathrm{mCp}\Delta\mathrm{T} = \frac{7482\mathrm{kg}}{\mathrm{day}} \times 17.97\mathrm{M}\frac{\mathrm{J}}{\mathrm{KgK}} \times (298 - 273)\mathrm{K} = 3.361 \times 10^{7}\mathrm{W} \ldots\ldots (7)$$

Inlet stream enthalpy is therefore $\mathrm{Q} + 3.361 \times 10^{7}\mathrm{W}$

Outlet stream

$$\mathrm{Q}_{out} = \mathrm{m\,C_P}\Delta\mathrm{T} = 8600\frac{\mathrm{kg}}{\mathrm{day}} \times 17.97\mathrm{M}\frac{\mathrm{J}}{\mathrm{KgK}} \times (383 - 273)\mathrm{K} = 16.997 \times 10^{7}\mathrm{W} \ldots\ldots (8)$$

$$\text{Heat in water vapour} = \mathrm{mCp}\Delta\mathrm{T} = 1118\frac{\mathrm{kg}}{\mathrm{day}} \times 4184\frac{\mathrm{J}}{\mathrm{KgK}} \times (383 - 273)5.95 \times 10^{4}\mathrm{W} = 5.95 \times 10^{4}\mathrm{W} \ldots\ldots (9)$$

Outlet streams enthalpy $= 5.95 \times 10^{4}\mathrm{W} + 16.997 \times 10^{7}\mathrm{W} = 22.93 \times 10^{7}\ \mathrm{W}$ ……(10)

Overall balance

$$(\mathrm{mC_p}\Delta\mathrm{T})_{\mathrm{inlet}} + \mathrm{Q} = (\mathrm{mC_p}\Delta\mathrm{T})_{\mathrm{outlet}} + (\mathrm{mC_p}\Delta\mathrm{T})_{\mathrm{vapour}} \ldots = 22.93 \times\ 10^{7} Watts -\ 3.361 \times 10^{7} Watts \ldots (11)$$

$$\mathrm{Q} = 19.56 \times 10^{7}\mathrm{W} \ldots (12)$$

4.3.2 Energy balance for the reactor

$$Q = m\ Cp\ \Delta T = \frac{7428\mathrm{kg}}{\mathrm{day}} \times 17.97\frac{\mathrm{MJ}}{\mathrm{KgK}} \times (748 - 298)\mathrm{K}\frac{}{3600\mathrm{s}} = 16\ 685.14\frac{\mathrm{kJ}}{\mathrm{S}} \ldots\ldots (13)$$

4.3.3 Energy balance on the pump

The energy supplied on the pump is being transferred as work.

$$\Delta H +\ \Delta E +\ \Delta P = Q + W \ldots\ldots (14)$$

Where: ΔH= Change in enthalpy, ΔE=Change in kinetic energy, ΔP= Change in potential energy, Q= Heat transfer and W= Work done.

Taking a velocity of 15ms^{-1} and a height of 2m

$$\Delta E\ = \frac{1}{2}mv^{2} = \frac{1}{2} \times 1472 \times \frac{15}{3600}\ = 3.07\ \text{Watts} \ldots\ldots (15)$$

$$\Delta P = mgh = \frac{1472\times9.81\times2}{3600} = 8.02\ \text{Watts} \ldots\ldots (16)$$

Considering that g is 9.81 m/s^2 and that ΔE+ΔP=W. The total work done is therefore 11.09 watts.

4.3.4 Energy balance on the crusher

Assuming an average size reduction of 100 um diameter of solid sludge to 75 um uses effective energy of 16 kW (kg/s), for reduction of size from 84.4 um to 32 um. Assuming that Rittinger's law applies:

$E = KpFc\ (\frac{1}{L2} - \frac{1}{L1})$………………………………………………………………………………………. (17)

Therefore:

$16 = KpFc\ (\frac{1}{75} - \frac{1}{100})$……………………………………………………..……………..……………(18)

$KpFc$ = 16/ [(1/75) – (1/100)] ………………………………………………………….………………………. (19)

E = kpfc [(1/32) – (1/84.4)] = 1034.7 KJ/ kg…………………………………...………………………… (20)

4.3.5 Energy balance on the sieve

Rittinger's Law assumes that the energy required for size reduction is directly proportional to the change in surface area.

$E = KpFc\ (\frac{1}{L2} - \frac{1}{L1})$ = kpfc [(1/32) – (1/84.4)] = 1034.7 KJ/ kg…………………….……………………. (21)

5. Site Selection and Plant Location

Site selection considers the parameters for the plant setting purposes including its arrangement of the pieces of equipment. Site selection involves measuring the needs of a new project against the merits of potential locations. There must also be a good scope for plant expansion. The plant site must be located where the cost of production and distribution is at a minimum level.

5.1 Factors affecting site selection

The factors that affect site selection include: raw materials availability, transport facilities, availability of labour and availability of utilities such as water, fuel, power and local community considerations. In addition, climate, Government policies, disaster preparedness, availability of suitable land, environmental impact, effluent disposal, market study, waste disposal, taxation and legal restrictions.

5.2 Plant Location

The plant location has an effect on the profitability of the process and the scope for future expansion. The location of the biochar plant was influenced by minimum production and distribution costs, Government policies, room for expansion and safe living conditions of the surrounding community. The Chitungwiza sewage treatment plant is located along Chitungwiza road; the plant is approximately 1 km away from the residential area of St Mary's. The plant provides employment and infrastructural development to the surrounding communities of Seke and St Mary's. The decision matrix for site selection ranking is shown in Table 4.

Table 4. Decision matrix on the site selection for biochar plant location

Decision parameter	Rating (%)	Chitungwiza (%)	Harare (%)
Raw materials	30	30	20
Site suitability	20	17	15
Water availability	10	8	5
Labor availability	10	8	5
Market	10	7	6
Transport availability	20	15	10
Total score	100	85	61

From the rating of the two possible sites, the Chitungwiza site was chosen because it has the highest percentage rating of 85%. Thus the plant will be located near to the waste water treatment plant.

5.3 Plant layout and factors to consider

Plant layout refers to the arrangement of physical facilities such as machines, equipment, tools and furniture in a manner so as to have quickest flow of material at the lowest cost. The plant layout must have the least amount of handling in processing the product from the receipt of raw material to the delivery of the final product. The process units and ancillary buildings should be laid out to give the most economical flow of materials and personnel. The factors to consider include: operating costs, process requirements, convenience of operation, placement of major plant components, transportation, convenience of maintenance, safety and future expansion.

6. Economic Analysis

The purpose of an economic assessment is to determine the economic and financial viability of the project using initial estimate of the costs and profits. The economic assessment also covers assumptions on financing estimation of project costs (fixed costs and working capital), estimation of manufacturing unit costs and calculation of annual net cash flows for biochar production.

6.1 Capital investment

The capital investment is money required before the biochar plant is put into operation. The land and service facilities to be erected with piping, controls and services must all be considered. Capital investment is divided into fixed capital investment and working capital.

6.1.1 Fixed capital investment

Fixed capital investment is capital needed for the installation of the process equipment with all auxiliaries that are required for complete process operation. Fixed capital investment can be further divided into direct costs and indirect costs.

6.1.2 Direct costs

The direct costs normally include the material and labour involved in actual installation of complete facility. Prices were obtained from Alibaba.com and cost indices were also used to approximate the cost of the equipment needed to install the plant. The bill of quantities on each piece of equipment were prepared to come up with actual cost fabrication as indicated in Table 5.

Table 5. Biochar plant purchased equipment costs

Equipment	Quantity	Cost (USD/unit)	Total cost (USD)
Chemical storage tanks	4	3000	12000
Air preheater	1	3500	3500
Crusher	1	3000	3000
Flow meters	3	80	240
Level meters	4	80	320
Valve	18	60	1080
Pipes	20	40	8000
Pyrolysis reactor	1	12500	12500
Drier	1	18200	18200
Pump	3	900	2700
Activation unit	1	11300	11300
Bar screens	3	2000	6000
Sieve	1	2500	2500
Gas compressor	1	800	800
Total			82140

The direct costs for biochar production is shown in Table 6.

Table 6. Direct costs for biochar production

Item	Range (%)	Chosen	Cost (USD)
Equipment	100	100	82140
Delivery	30 – 40	30	24642
Installations	20 -40	20	16428
Instrumentation and control	15 – 30	15	12321
Yard improvement	5 – 10	5	4105
Buildings and electricals	10 – 50	10	8214
Piping	10 – 30	10	8214
Total			156066

6.1.3 Indirect costs

Indirect costs are expenses that are not directly involved with material and labour of actual installation of complete plant. The total indirect costs calculation is represented by Equation 22.

$$Fixed\ capital\ investments = Direct\ costs + Indirect\ costs = USD\ 203\ 425.80 \ldots\ldots\ldots\ldots \quad (22)$$

6.2 Working capital

The working capital for the biochar plant will consist of the total amount of money invested in producing biochar. Assuming 15% of the Total Capital investment. The total working capital is represented by Equation 23.

$$Working\ capital = 15\%\ of\ Total\ capital\ investment = USD 35\ 898.67 \ldots\ldots\ldots\ldots\ldots \quad (23)$$

6.3 Total production costs

The total production costs provide estimated percentages of all costs involved in the complete operation of a plant that are applicable to the treatment process. Total production costs are broken down into manufacturing cost and general expenses as indicated in Equation 24. The total production cost is a sum of the total manufacturing cost and the general expenses. For this study, the total production cost was USD 123 384.85 from a total of USD 20791.41 and USD 102593.43.

$$Total\ production\ cost\ =\ Total\ manufacturing\ cost\ +\ General\ expenses \ldots\ldots\ldots\ldots \quad (24)$$

6.4 Manufacturing costs

The manufacturing costs are classified into operating costs, fixed charges and plant overheads. The major raw material is waste sewage sludge so there is no cost of raw materials. The total manufacturing costs are given by Equation 25.

$$Total\ manufacturing\ costs\ =\ Plants\ overheads\ +\ Fixed\ charges\ +\ Variable\ costs \ldots\ldots \quad \ldots\ldots (25)$$

The plant overhead costs are shown in Table 7.

Table 7. Plant overheads for biochar production

Cost description	**Range %**	**Chosen**	**Cost (USD)**
Canteen	10-20 TCI	10	23932.42
Payroll overhead	10 FCI	10	20332.48
Storage facilities	2-3 TCI	2	4786.49
Medical services	1-4 FCI	1	2034.26
Safety and protection	1-4FCI	2	4068.52
Total			55 154.17

The fixed charges for biochar production are shown in Table 8.

Table 8. Fixed Charges

Item	**Range (%)**	**Cost (USD)**
Depreciation	4.0FCI	7587.78
Taxes	1.0FCI	2034.26
Insurance	0.4CI	813.70
Rent and taxes	0.8FCI	1627.41
Total		12 063.15

The variable costs for biochar production are shown in Table 9.

Table 9. Variable Costs

Item	Range (%)	Cost (USD)
Raw materials	1 DC	1560.66
Operating labor	4 DC	6242.64
Plant utilities	5 TCI	11966.21
Maintenance and repair	2 DC	3121.32
Patents and royalties	3 DC	4681.80
Direct supervisory and clerical	5 DC	7803.30
Total		35 376.11

$$Total\ manufacturing\ costs\ =\ Plants\ overheads\ +\ fixed\ charges\ +\ Variable\ costs = USD102\ 593.43\ \ldots\ldots(26)$$

The general expenses for biochar production from sewage sludge are shown in Table 10.

Table 10. General expenses

Cost description	Range (%)	Chosen	Cost (USD)
Research and development	5TMC	5	5129.67
Administrative costs	2-6TMC	4	4103.74
Interest	0-6TMC	2	2051.87
EMA	1 TCI	1	2393.24
EIA Consultancy	0.4 TCI	0.4	957.30
Distribution and selling	0-15 TMC	8	8203.44
Total			20791.42

6.5 Gross earnings

The gross earnings refer to the total income earned prior to the application of any tax deductions or adjustments. It can also be defined as the amount left over from total revenues over a specified time period once the cost of goods sold has been deducted.

6.6 Production price

The production price was determined after assuming that 9600 kg/day of sewage sludge was being produced and 365 working days. A profit margin of 90% was also assumed and also taxes. A summary of parameters used to determine the production price is given in Table 11.

Table 11. Summary for calculation of production price

Item	Value
Annual Production in kg	3 504 000 kg
Total cost of production	USD123 384.85
Production cost/kg	$= \frac{USD\ 123\ 384.85}{3504000kg} = USD\ 0.035/kg$

Selling price	$= \frac{190}{100} \times USD0.035 \quad = USD0.07$
Total income	USD 233 016.00
Total revenue= Total income	USD 233 016.00
Gross income=Total revenue-TPC	= USD 233 016.00 - USD 123 384.85=USD 109 632.15
Taxes = 10% of gross earnings	= 0.10 x USD109 632.15= USD10 963.21
Net Profit-= Gross income – Taxes	= USD 109 631.15 - USD 10 963.21= USD 98 668.04

6.7 Return on investment

Return on investment (ROI) is the measure, per time, rates of return on money invested in an economic entity in order to decide whether or not to undertake an investment. The ROI for this study is given in Equation 27.

$$ROI = \frac{Net\ profit}{Total\ Capital\ investment} \times 100\% = \frac{USD98668.04}{USD239\ 324.27} \times 100 = 41.2\% \quad (27)$$

6.8 Net present value

The net present value (NPV) is the sum of money in contrast to some future value it may have when it has been invested at compound interest. The NPV calculation for this study is given by Equations 28 and 29.

$$NPV = Total\ present\ value\ of\ cash\ flows - Initial\ investment$$

$$= \left[\frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \frac{R_3}{(1+i)^3} + \cdots\right] - Initial\ investment \quad (28)$$

Where: i is the target rate of investment per period; R_1 is the net cash inflow during the first period; R_2 is the net cash inflow during the second period and R_3 is the net cash inflow during the third period.
The NPV factors for conversion of sewage sludge to biochar is given in Table 12 over a 5-year period.

Table 12. Present value factors for biochar production

Year	Calculation	PV factor
1	$\frac{1}{(1+0.412)^1}$	0.708
2	$\frac{1}{(1+0.412)^2}$	0.502
3	$\frac{1}{(1+0.412)^3}$	0.355
4	$\frac{1}{(1+0.412)^4}$	0.252
5	$\frac{1}{(1+0.412)^5}$	0.178

The cash flow forecast over 5 years is given in Table 13.

Table 13. Cash flow forecast for biochar production

Year	Cash flow (USD)	Present value factor	Present value (USD)	Cumulative cash flow (USD)
1	233016.00	0.708	164975.33	164975.33
2	233016.00	0.502	116974.03	48001.30
3	233016.00	0.355	82720.68	(-34719.38)
4	233016.00	0.252	58720.03	(24000.64)
5	233016.00	0.178	41476.85	(17476.20)

$$NPV = Total\ present\ value\ of\ cash\ flows - initial\ investment = USD261441.12 \quad (29)$$

6.9 Payback period

Payback period is the time required for the cumulative net cash flow taken from start-up of the plant to equal the fixed capital investment. The payback period is based on the premise that the earlier the fixed capital is recovered the better the project and is calculated in accordance to Equation 30.

$$Payback\ period = \frac{Total\ Capital\ Investment}{Net\ Profit} = \frac{USD239\ 324.27}{USD98\ 668.04} = 2.4\ years \quad (30)$$

6.10 Breakeven point

The breakeven point refers to the point whereby the total costs equals the total revenue, at this point there is no net loss or gain. The breakeven point is given as discussed in Equation 31.

$pv = vx + FC + Profit$………………………………………………………………………..…… (31)

Where: p is price per unit, **x** is number of units, **v** is variable cost per unit and FC is total fixed cost.
Assuming at breakeven profit will be zero, equation is written as indicated in Equation 32.

$px = vx + FC$…………………………………………………………………………………………… (32)

The break-even point in units and in dollars are as represented by Equation 33 and 34.

Break-even point in units= $\frac{\mathrm{FC}}{\mathrm{p-v}} = \frac{USD203\ 425.80}{3.00-0.06} =$ 62 192.45 units……………………………………………(33)

Breakeven point in dollars $= \frac{USD203\ 425.80}{\frac{3-0.06}{3}} = USD207\ 577.35$…………………………………………….(34)

The break-even chart summary is shown in Figure 5.

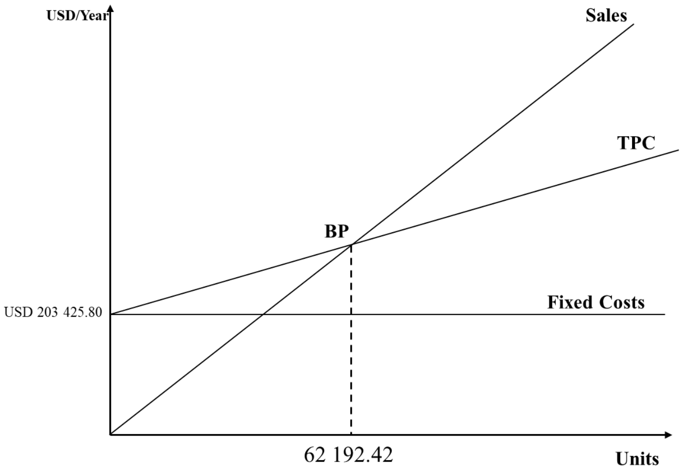

Figure 5. Break even chart for biochar production from sewage sludge

7. Conclusion

Biochar from sewage sludge was successfully produced with a yield of 58% and surface area of 240 mg/g. An economic assessment for a plant that processes 9600 kg/day into biochar showed that the process is economically viable with a 41.2% return on investment and a payback period of 2.4 years. In addition, the breakeven in dollars was USD207577.35 and an NPV of USD261441.12.

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