Design and Fabrication of Biomass Turbine Generator

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Abstract— *Biomass is a renewable energy source that is sustainable and also provides solution to the growing pollution problem. Poor electricity production in Nigeria is a major contributor to the country's low industrial development, despite the fact that the country is endowed with oil and other numerous natural resources. This might get worse as the country's population keeps increasing added to more energy demand by the ever expanding industrial sector. Biomass for heat and power production holds a large potential as a source of renewable energy and reduction of greenhouse gas emission. If energy derived from renewable energy sources is added to the current energy supply in the country, it could be enough to place the country in the category of industrial nations without significant increase in environmental pollution. Sawdust which is treated as waste in Nigeria because of its low burning efficiency could be used to power steam turbine for production of electricity. In this way, power production in the country will be increased. The aim of this study is to design and fabricate a biomass steam turbine that will use sawdust as its source of fuel to produce electricity.*

Keywords— Biomass, Renewable Energy, Sawdust, Steam Turbine, Electricity.

I. INTRODUCTION

Low energy production persists in Nigeria despite the fact that the country is endowed with oil and other natural resources. Adeola (2003) pointed out that electricity generation, transmission and distribution accounts to less than one percent (1%) of the country's gross domestic product (GDP) and 50% of utility supply. Currently, energy supply in Nigeria is estimated at 41% indicating that demand for energy outweighs its supply. The Federal Government is deeply concerned about this problem and is making efforts to increase power supply to the country.

However, if energy is to be produced from renewable energy sources and added to the current energy supply, the country may achieve self-sufficiency in energy which can place her among the category of the industrial nations. This can be achieved without significant increase in environmental pollution (Olaoye *et al.*, 2016). According to Wilson (2010), biomass for heat and power production holds enormous potentials as a source of renewable energy and greenhouse gas emission reductions, but this potential is only being realized at a slow pace. As the population of the country is increasing, energy consumption also will increase and the only solution is to increase power production. The gradual decreasing of fossil fuels and its negative effect on the atmosphere by causing global warming and climate change have made nations to resort to alternative energy sources to meet their energy demands and to save the ecosystem. Also, carbon based non-renewable energy is unsustainable (RC, 2004; Akintunde, 2002; Adegoke and Akintunde, 2003; Emevon, *et al*., 2010).

However, Nigeria still depends on the off-grid supplies for her energy needs thereby running at high overhead costs. This has caused many businesses to wind up and some others to relocate from Nigeria to other countries where energy cost is relatively lower. The issue remains how the energy crisis in the country could be solved whilst taking into consideration environmental conservation, since atmospheric pollution, carbon loading and climate change have put humanity at a high risk. It is therefore imperative that usage of non-renewable energy sources should be controlled.

1.1 Biomass

Biomass refers to renewable organic materials that come from living organisms such as plants and animals (Kirk, 2011). There are varieties of biomass, the most popular being wood. A biomass system uses the energy generated when burning wood pellets (or briquettes), wood chips or logs in a biomass boiler to generate heat and/or energy. This can be used to power hot water systems, central heating or to heat spaces. Sawdust is by–product from wood sawing process. Actually, sawdust doesn't have much application because of its low burning efficiency however, by pressing it into pellets; it becomes a kind of high quality biofuel product – sawdust pellets or wood pellets (Kirk, 2011).

More and more countries are seeking solutions to produce thermal energy from renewable sources as it represents the most affordable and durable resource for production of heat and electricity (Chukwuma *et al.* 2013; Umeghalu *et al.* 2015). Biomass comes from many different sources, but the most common sources of biomass are: forest harvests and agricultural residue like wheat straw and energy crops, municipal and industrial waste.

1.2 Biomass fuel

Biomass contains stored chemical energy from the sun that is produced through photosynthesis and can be burnt directly for heat or converted to liquid and gaseous fuels. In biomass power plants, wood waste or other waste is burnt to produce steam that runs a turbine to produce electricity, or heat for industries and homes. Fortunately, new technologies including pollution control and combustion engineering have advanced to the point that emission from burning biomass in industrial facilities are generally less than emissions produced when using fossil fuels such as coal, natural gas and oil.

Biomass is a renewable energy source not only because the energy in it comes from the sun, but also because biomass can replenish within relatively short period of time compared with the hundreds of millions of years that it took fossil fuels to form. Biomass for heat and power holds a large potential as a source of renewable energy and greenhouse gas emission reductions, but this potential is only being realized at a slow pace today. It is therefore necessary to carry out further research in its improvement, use and its application for electricity generation. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates a complex compound composed of carbon, hydrogen, and oxygen. When these carbohydrates are burnt, they turn back into carbon dioxide and water and release the energy they captured from the sun.

Biomass fuels provided about 4 percent of the energy used in the United States in 2010, in which about 46% was from wood and wood-derived biomass, 43% was from biofuels (mainly ethanol), and about 11% came from municipal waste. Many researchers are working to develop ways to burn more biomass and fewer fossil fuels. Using biomass for energy cuts back on waste and greenhouse gas emissions. Biomass offers other significant environmental and consumer benefit, including improving the forest, health by protecting air quality, and offers the most dependable renewable energy source.

Biomass energy production is beneficial to the environment preserving ecosystems and assuring sustainable future. There is need to produce biomass energy in sustainable and ecologically safe way, with little or no pollution to air, water or soil. Yogesh, (2007), listed the main advantages and disadvantages of biomass as follows:

A. Advantages of biomass production.

(i). Sustainable source;

Biomass energy uses organic material and waste for its production. Crops and residues from agriculture and forests are sustainable source of biomass. Managing the resources is important to assure sustainability principle.

(ii). Renewable source:

Crops, wood, agricultural residue, can be harvested year after year. Unlike fossil fuel reserves, biomass reserves will always be available.

(iii). Reducing pollution:

Biomass combustion process emits far less greenhouse gasses into the air than in fossil fuel combustion process. In the process of "gasification" no pollution gasses are emitted into the air.

B. Disadvantages of biomass energy production:

(i). Resource management: if not managed correctly, forests and land can be used to grow energy crops instead of food production.

(ii). Direct and indirect CO_2 emission: combustion of biomass can contribute to higher carbon concentration in the air.

Trees take CO_2 from the atmosphere during their whole life. This CO_2 is released when the trees are burnt or during natural decay. Moreover, carbon is produced through planting, harvesting, processing an timber processing, as well as through the manufacturing and delivery of wood pellets. Biomass fuel is quite different compared to the coal. Biomass is highly oxygenated typically; 30-40% of the dry matter in biomass is oxygen (Jenkins et al., 1998). According to Chagger et al. (1998), the volatile matter in biomass is 3 or 4 times higher than that in coal, while the fixed carbon is lower, which is only 14%-22% in weight of biomass compared to 77% in coal. Another important character is element sulphur, which is very low content in biomass. Hence, biomass is believed to be less harmful to the environment.

The heat value, or amount of heat available in a fuel (kJ/kg), is one of the most important characteristics of a fuel because it indicates the total amount of energy that is available in the fuel (RC, 2004). The heat value can be expressed in one of two ways: the higher heating value (HHV) or the lower heating value (LHV). The higher heating value (HHV) is the total amount of heat energy that is available in the fuel, including the energy contained in the water vapor in the exhaust gases. The lower heating value (LHV) does not include the energy embodied in the water vapor. The heat content of different species can vary significantly depending on the climate and soil in which the fuel is grown, as well as other conditions (The Pennsylvania State University, 2010).

1.3 Water

Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder (Krik, 2011), This causes the boiler to be extremely dangerous equipment that must be handled with utmost care. The process of heating a liquid until it reaches its gaseous state is called evaporation.

1.4 Steam Turbine

In general, a **steam turbine** is a rotary heat engine that converts thermal energy contained in the steam to mechanical or electrical energy. A **steam turbine** consists of a **boiler (steam generator), turbine, condenser, feed pump** and a variety of auxiliary devices. Unlike with reciprocating engines, for instance, compression, heating and expansion are continuous and they occur simultaneously. The basic operation of the steam turbine is similar to the gas turbine except that the working fluid is water and steam instead is air or gas. S**team turbine** as a rotary heat engine is suited to be used to drive electrical generator. About **90%** of all electricity generation in the world is by use of steam turbines. Steam turbine is powered by the energy in hot, gaseous steam. It has spinning blades that turn when steam blows pass them. The blades are fitted strongly inside a sealed outer container so that the steam is constrained and therefore forced to pass through them at great speed.

1.4.1 Types of Turbines.

According to shaft position, turbines can be classified as horizontal or vertical; while according to the method of drive, they can be classified into direct connected or geared. Also according to the action of steam turbines are classified as impulse or reaction turbines. Meanwhile, according to exhaust pressure they are classified as non-condensing or condensing extraction.

1.4.2 Impulse turbines.

In impulse turbine, the rotating blades are shaped like buckets. Impulse turbine is designed in such a way that when high-velocity jets of incoming steam from carefully shaped nozzles kick into the buckets, pushing them around with a series of impulses, they however bounce off to the other side at a similar speed but with much-reduced pressure in comparison to the incoming jet. Impulse turbine is good for extracting energy from high-pressure steam.

1.4.3 Reaction turbines:

In reaction turbines, there are second set of stationary blades attached to the inside of the turbine case. These help to speed up and direct the steam onto the rotating blades at just the right angle before it leaves with reduced temperature and pressure, but broadly with the same speed it had when it entered. However, in both cases, the steam expands and gives up some of its energy as it passes through the turbine. Ideally, all the heat and kinetic energy lost by the steam would be gained by the turbine and converted into useful kinetic energy that makes it to spin around. But, of course, the turbine will be heated up while some steam might leak.

Apart from the rotor and its blades, a turbine also needs some sort of steam inlet consisting usually of set of nozzles that direct steam onto either the stationary or rotating blades. Steam turbines also need some form of control mechanism that regulates their speed, so that they generate as much or as little power as needed at any particular time.

PLATE 1: Condensing and Non-condensing

Turbines also vary according to how they cool the steam that passes through them. Condensing turbines used in large power plants to generate electricity turn the steam at least partly to water using condensers and giant concrete cooling towers. This allows the steam to expand more and it helps the turbine to extract maximum energy from it. This makes the electricity generating process to be much more efficient. However, large supply of cold water is needed to condense the steam, and that's why electricity plants with condensing turbines are often built next to large rivers. But non-condensing turbines do not cool the steam so much as they use the heat remaining in them to keep water hot in the system. this system is known as combined heat and power (CHP) or cogeneration.

1.5 Losses in Steam Turbines

The steam turbine is not a perfect heat engine. Energy losses tend to decrease the efficiency and work output of a turbine. This inefficiency can be attributed to the following causes.

1) Residual Velocity Loss:

The velocity of the steam that leaves the turbine must have certain absolute value (v_{ex}). The energy loss due to absolute exit velocity of steam is proportional to (v_{ex}^2). This type of loss can be reduced by using multistage turbine.

2) Presence of Friction:

In real thermodynamic systems or in real heat engines, a part of the overall cycle's inefficiency is due to the frictional losses by the individual components (e.g. nozzles or turbine blades).

3) Steam Leakage:

The turbine rotor and the casing cannot be perfectly insulated. Some amount of steam leak from the chamber without performing useful work.

4) Loss Due to Mechanical Friction in Bearings:

Each turbine rotor is mounted on two bearings, i.e. there are double bearings between each turbine module.

5) Losses Due to Low Quality of Steam:

The exhausted steam is at a pressure below atmospheric pressure and the steam is in a partially condensed state, typically of a quality near 90%. Higher content of water droplets can cause the rapid impingement and erosion of the blades which occurs when condensed water is blasted onto the blades.

6) Radiation Loss:

Steam turbine may operate at steady state with inlet conditions of 6MPa, t = 275.6°. Since it is a large and heavy machine, it must be thermally insulated to avoid any heat loss to the surroundings.

II. MATERIALS AND METHODS

2.1 Materials used for the construction:

The materials used for the fabrication of the biomass steam turbine generator are: mild steel plate, mild steel bars, angle mild steel bars, cylindrical tubes, aluminums plates, pressure pipes, stainless electrodes, valves, pressure gauge, bolts and nuts, light bulbs and lamp holder, thread tape, plank, paints, saw dusts and charcoal. All these materials were locally purchased.

2.2 Construction of heat exchanger along the chimney:

Heat loses from the heat exchanger is avoided by creating a double step along the smoke-rail which aids heat retention of the boiler and reduces heat losses. These losses if not checked could affect the output and durability of the electricity generated by the steam generator.

2.3 Construction of a charcoal pot fuel chamber

The marking out tools were used to mark out and then cut to detailed measurement of the fuel chamber from the mild steel sheet. The cut mild steel was folded using the hand folding machine a circular disc was also cut out of the mild steel sheet. A semi-cylinder that was cut out of the big combustion chambers cylinder was welded to the side of the cylinder. An opening of 10cm diameter was made at the centre of the circular disc. That same circular disc was also welded to the bottom of the cylinder**.**

2.4 Design Calculations

Below are some important parameters that need to be considered in determining the appropriate size of the biomass steam turbine generator, taking into consideration the power output desired. The size of the stove can be easily estimated by computing these parameters.

The following parameters and their formula are used to calculate the basic requirement in the design of the biomass steam turbine:

1) Stress in the boiler shell

$$\delta = \frac{PD}{2t}$$

Where,

P= pressure of the steam, D= diameter of the water pot, T= the thickness

2) Moisture content

$$\frac{w_1 - w_2}{w_1} \times 100$$

Where,

w_1 = weight of the sawdust on wet basis

w_2 = weight of the of the sawdust on dry basis

When the sawdust was wet, it weighed (w_1) = 3kg

When dried, it weighed (w2) = 2.4kg

3) Circumference of a circle: 2πr

4) Surface area of the water cylinder

$$2\pi r^2 + 2\pi r = 2\pi r\ (r + h)$$

5) Water capacity of the boiler = $\pi r^2 h$

6) Volume of the cylinder: $v = \pi r^2 h$

r = radius of the cylinder

h = height of the cylinder

7) Force acting in the water cylinder: $F = PA = P\pi r^2$

III. RESULTS AND DISCUSSION

Using 13litres of water and 100% charcoal the following procedures were carried out:

1. 13 litres of water was boiled using 100% charcoal.
2. After an interval of 10mins, the pressure attained was recorded. At 40mins, the steam attained a pressure of 8bars.
3. The inlet valves were opened to allow inflow of steam to the turbine.
4. The voltage and current generated by the steam turbine over a period of time were recorded as pressure drops by 1bar.

3.1 Results

Table 1 below compares the time it takes to attain pressure sufficient to run the steam turbine over a period of time using 100% charcoal and 100% sawdust as fuel

TABLE 1
COMPARISON OF STARTUP PRESSURE USING CHARCOAL WITH THE USE OF SAW DUST IN THE DESIGNED BIOMASS STEAM TURBINE.

S/N	Time Interval (min.)	Pressure (bar) 100% charcoal	Pressure (bar) 100% saw dust
1	0	0	0
2	10	0.8	0
3	20	3.5	1.8
4	30	6.2	4.0
5	40	9.2	7.1

TABLE 2
COMPARISON OF STARTUP PRESSURE USING CHARCOAL WITH THE USE OF SAW DUST IN THE DESIGNED BIOMASS STEAM TURBINE.

S/N	Time interval (min.)	Pressure (bar)	Rate (bar /min)
1	0	9.2	-
2	5	8.9	1.78
3	10	8.4	0.84
4	15	7.5	0.50
5	20	6.3	0.32
6	25	4.6	0.18
7	30	2.6	0.09
8	35	0.3	0.009

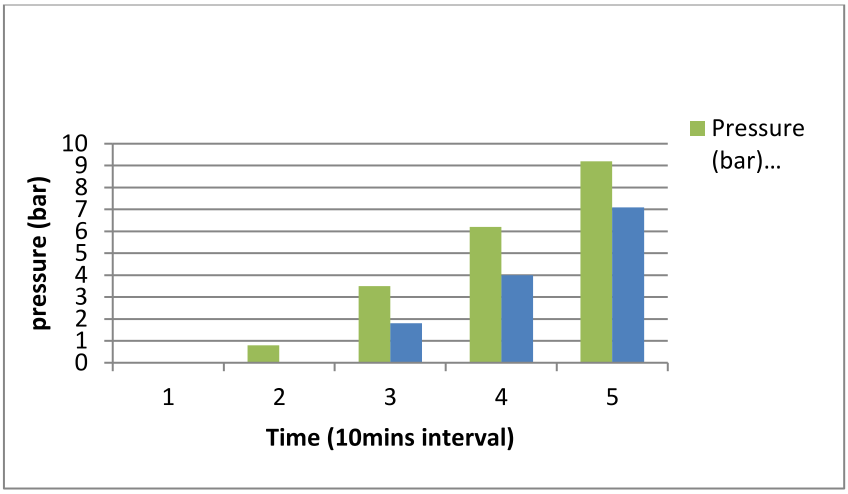

FIGURE 1: Graph of comparison of startup pressure between using charcoal and using saw dust in powering the steam turbine.

Table 1 and Fig 1 compares the time it takes to attain pressure sufficient to run the steam turbine over a period of time using 100% charcoal and 100% sawdust as fuel. Result obtained shows that the startup time is reduced when using charcoal as fuel. This is because charcoal has a higher calorific value when compared to sawdust.

TABLE 3
VOLTAGE, CURRENT AND POWER PRODUCE FROM THE STEAM TURBINE WITH TIME

S/N	Time interval (min)	Voltage (V)	Current (Amp.)	Power (watts)
1	0	150	0.063	9.450
2	5	146	0.062	9.052
3	10	140	0.061	8.540
4	15	126	0.060	7.560
5	20	105	0.060	6.300
6	25	80	0.058	4.600
7	30	40	0.055	2.200
8	35	23	0	0

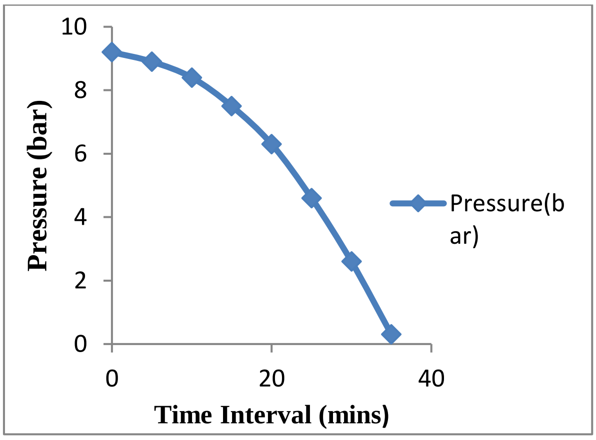

FIGURE 2: Graph of rate of decrease in pressure with respect to time.

Also, Table 2 and Fig 2 illustrates the duration of the electricity generated and the rate of decrease in pressure. It was found that power was generated over a period of 35 minutes as opposed to the time it lasts initially which was less than a minute. The table also shows the rate at which pressure drops with respect to time. It was observed also that it affects the rate of decrease in the power generated.

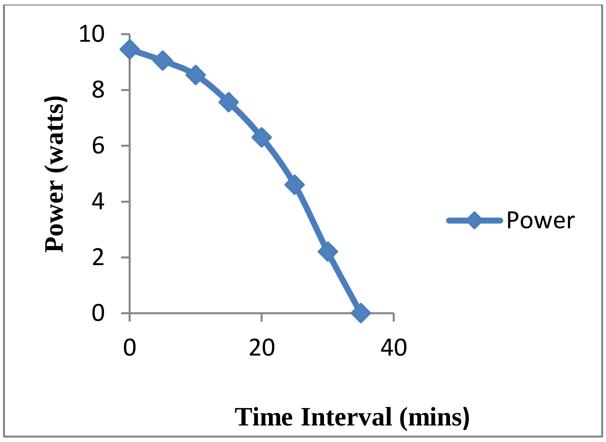

FIGURE 3: Graph of power decrease with time.

Table 3 represents the voltage, current and power generated by the biomass steam turbine. The power is seen to decrease with respect to time. Fig 3 represents the decrease of power generated with respect to time.

IV. CONCLUSION

Biomass steam turbine is an important invention in Nigeria today owing to the fact that less greenhouse gasses are released which results to low environmental pollution, as well as the fact that biomass is quite easy to source and a renewable source of energy. The modification carried out on the biomass steam turbine improved the longevity of the power generated by the system by increasing the pressure generated by the steam and the retention of heat produced. The startup time was greatly reduced by changing the source of fuel (sawdust) which has a low calorific value and replacing it with charcoal thereby producing heat sufficient to attain the desired pressure at shorter time duration. The machine's mobility was improved as well by changing the material (clay) used to lag the water chamber to sawdust. The power generated by the biomass steam turbine was also measured and this was able to power a LED lamp and also charge a phone over a longer period of time than it initially prior to the modification.

V. RECOMMENDATIONS

For the issue of power supply to be resolved in Nigeria, there is need for more research on biomass steam turbine especially in the following areas:

i. New design and fabrication of a continuous biomass steam turbine.

ii. The cost effectiveness of steam engine and other biomass.

iii. The efficiency of the biomass steam turbine.

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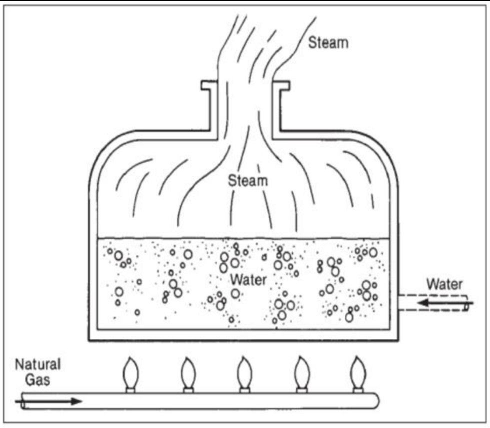
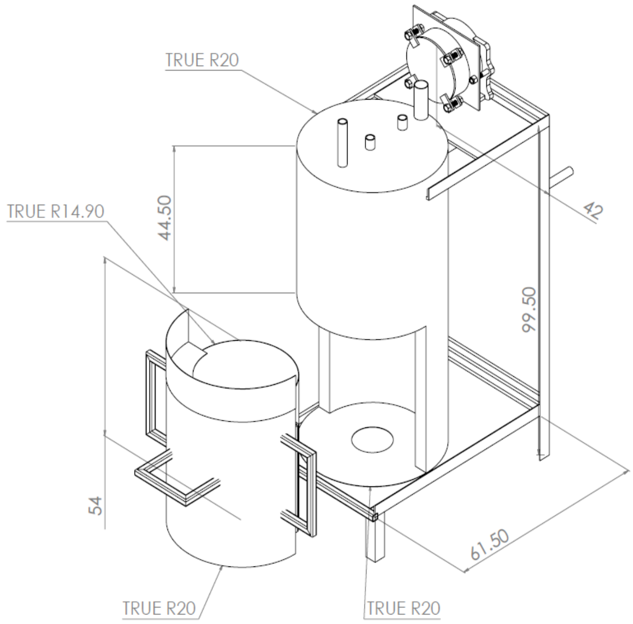
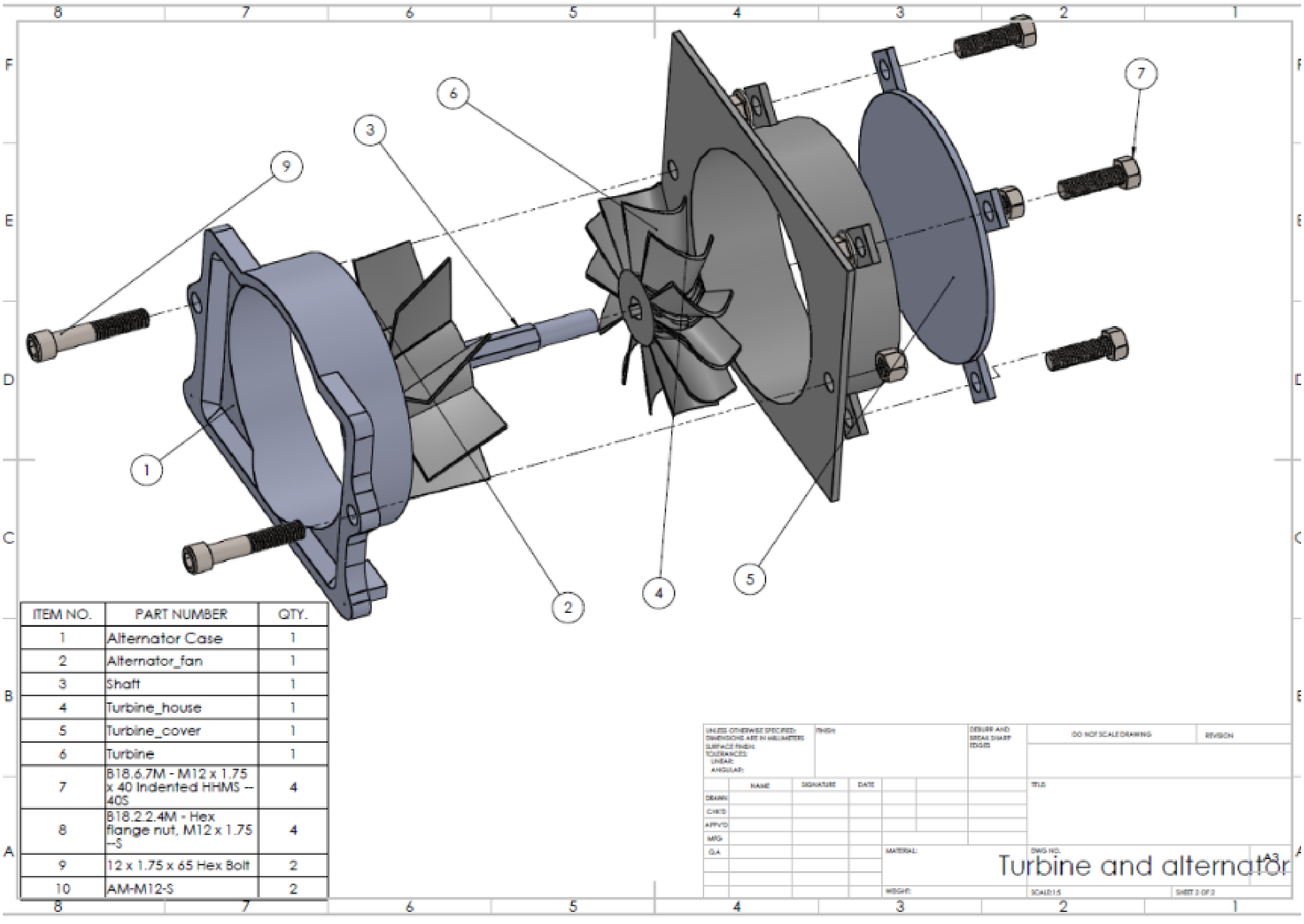
APPENDICES



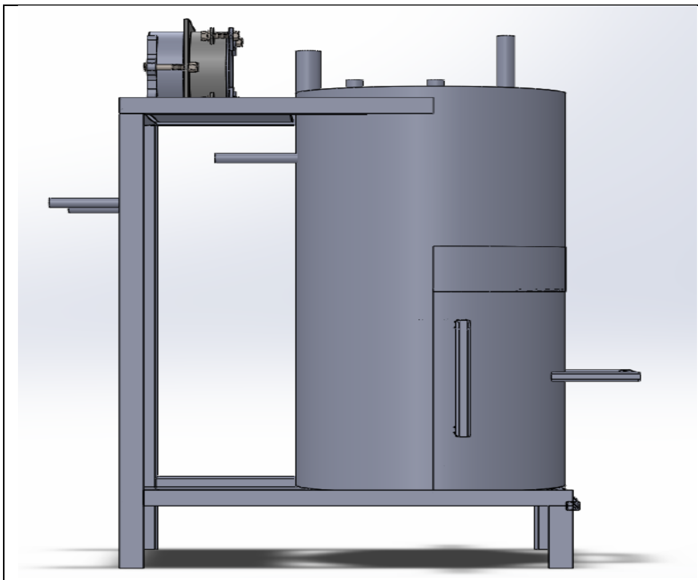
Appendix 1: The boiler and the gasification stove principle used for our design.



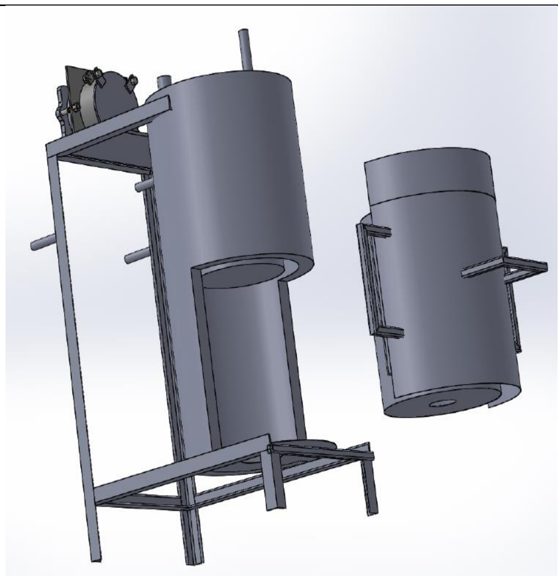
Appendix 2: Design of the steam turbine generator



Appendix 3



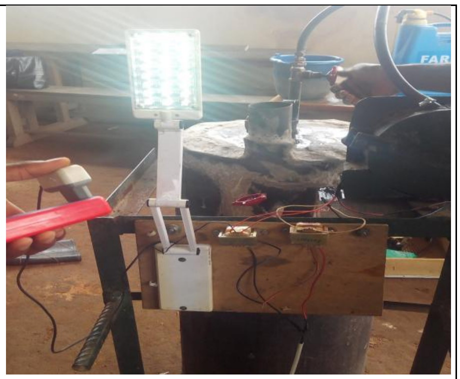
Appendix 4: The side view of the design



Appendix 5: 3D view of the turbine and the fuel chamber

Appendix 6: Turbine blades

Appendix 7: The fabricated gasification stove(fuel chamber)



Appendix 8: The light produced by the generator

Appendix 9:

Design calculations

i. **Stress in the boiler shell:**

$$\delta = \frac{PD}{2t}$$

Where, P= pressure of the steam, D= diameter of the water pot, T= the thickness

$$\delta = \frac{10 \times 24}{2 \times 0.2}$$

$$\delta = \frac{240}{0.4} = 600\text{bar}$$

ii. **Moisture content**

$$\frac{w1 - w2}{w1} \times 100$$

Where,

w1 = weight of the sawdust on wet basis

w2 = weight of the of the sawdust on dry basis

When the sawdust was wet, it weighed (w1) = 3kg

When dried, it weighed (w2) = 2.4kg

Therefore,

$$\frac{3-2.4}{3} \times 100$$

$\frac{0.6}{3} \times 100 = 0.2 \times 100 = 20\%$

Hence, the moisture content was 20%.

iii. **Circumference of a circle:** 2πr

iv. **Surface area of the water cylinder:**

$2\pi r^2 + 2\pi r$h $= 2\pi r\ (r + h)$

= $2 \times \pi \times 12$cm $(12$cm $+ 40.8$cm $= 24cm \times \pi \times (52.8cm)$

$= 1267.2\pi$cm $=3982.63$cm^2

- **Water capacity of the boiler** = $\pi r^2 h$

$3.142 \times 12^2 \times 29.2 = 3.142 \times 144 \times 29.2 = 13{,}215.08$cm^3

But 1cm^3=0.001litre

Therefore, the boiler water capacity =0.001×13,215.086 = 13.2litres.

- **Volume of the cylinder**, $v = \pi r^2 h$

r = radius of the cylinder = 12cm

h = height of the cylinder = 40.8cm

Therefore, $v = \pi \times 12^2 \times 40.8$

$= \pi \times 144 \times 40.8$

$= 5875.2\pi$

=18464.914cm^3

- **Force acting in the water cylinder**:

$F = PA$

$F = P\pi r^2$

F= $10 \times \frac{22}{7} \times 12^2$

F= 4.5kN