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Rice Husk as an Alternative Source of Energy for Green Electricity Generation in Nigeria

Oti Stephen Ejiofor [1], Okoro Prince [2*], Uche Ogbuefi C.[3], Obe Chinedu [4], Agada Stephen[5]

Department of Electrical Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria[1-4].
Dept. of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia[5] State. Nigeria
*Corresponding author: anthony.okoro.pg01001@unn.edu.ng

Abstract— Rice husk produced during rice milling is an important source of energy. The availability of rice husk in Adani in Uzo-Uwani Local Government Area of Enugu state, Nigeria was assessed and its energy potential was obtained. This information was used to design the gasification system with secondary producer gas purification capacity. The step by step analytical approaches for the design of the rice husk gasification power system were presented. The estimated total load demand of the study area is $850.054kW$. The estimated total daily, monthly and yearly energy demands of the study area are: 8991kWhr, 269736.42kWhr and 3236837.04kWhr. The annual availability of rice husk in the study area is $3{,}636\ tonnes\ per\ year$ and it has potential of $1.52MW$ power generation with daily, monthly and yearly energy generation of: 36.48MWhr, 1,094.4MWhr and 13,132.8MWhr respectively. This potential of electricity generation has power station capacity of 1.9MVA which is approximately equal to 2MVA. The gasification system was designed based on the mass flow rate of producer gas required to power the gas engine at full load. The gasifier was designed downdraft with air and steam as the oxidizing agent in order to maintain uniform temperature in the oxidation and reduction zones.

Keywords— Rice husk, gasification, energy demand, off-grid, electricity, mass balance.

1. Introduction

Nigeria is West Africa's largest producer of rice, producing averagely 3.1 million tonnes of rice paddy per annum [1]. In Nigeria, rice cultivation extends from northern to the southern zones with the eastern and middle belts having the greatest share [2]. Rice production in Nigeria is growing gradually and the demand has increased at a much faster rate do to population growth and urbanization [3]. During rice production, by-products like rick husk are generated in the rice milling process. This rice husk accounts for approximately 20% - 23% of the total rice paddy weight [4]. The quantity of rice by-products generated in Nigeria per annum was estimated to be about 1,032,993.6 metric tonnes [5]. Recently, the Federal Government of Nigeria has kin interest in agriculture as a means of diversifying Nigeria economy, thus; reducing over dependency on crude oil and rice is one of the agricultural products that have been given much attention. This implies that the quantity of rice husk production will also increase. Rice husk is abundant in Nigeria and has potential to generate many Megawatt of electricity; this has been reported severally in the literature [6 - 8]. Rice husk can be converted into energy products through two processes: thermo-chemical and bio-chemical processes. Thermo-chemical process can be done by: direct combustion, pyrolysis and gasification techniques [9]. Direct combustion technique involves burning of rice husk to produce heat used to heat water to steam and the steam will be used to drive steam turbine [10]. This technique is not economical and generates CO_2 which is dangerous to the health and environment [11], thus; making this technique not to be the best option for power generation. The second technique is the so called pyrolysis technique, the technology is expensive and involves controlled heating of rice husk in the absence of oxygen, it also produces large quantity of char which is not desirable [12]. This technique produces more of bio-oil than biogas [13], however if more biogas is needed with low cost, this technology will not be the best option. The third technique is by gasification technology. During gasification process, rice husk is directly converted to producer gas in a gasifier at a very high temperature (more than 700^0C) under a controlled amount of air or steam [14]. This is the best option for generation of green energy from rice husk [15-16]. Bio-chemical process involves the use of anaerobic digestion and fermentation techniques. This process is not good for power generation as anaerobic digestion takes a lot of time and fermentation is for ethanol production [17 - 19]. Among all these techniques it is obvious that gasification is an excellent option for rice husk off-grid power generation [20] and so, this paper centres on rice husk gasification technology for green electricity generation.

2.0 Literature Survey

For developing countries, a large number of researches have been done and a detail review of the literature may redirect the course of this paper. However, to mention a few, Shukla, Sunil, Rahul and Arun [21], conducted an experiment on 14kW rice husk gasifier system in Indian Institute of Technology (BHU) campus. Their project focused on substituting diesel consumption using producer gas from rice husk in dual fuel power generator. However, the study did not consider any traditional rural electrification and secondary filtering of the producer gas. Wu et al [22], analysed the economic feasibility of biomass gasification and power generation in China while Yin et al [23] reported the design and operation of a rice husk based circulated fluidised bed gasification and power generation system located in China. Their studies did not consider any traditional rural electrification. Gasification of moist rice husk in fluidised bed gasifier can increase the formation of contaminant of hydrogen sulphide, carbon iv oxide and ammonia which can lead to clog of the gasifier and the gas engine. Ha-Duong and Nam [24], studied Rice husk gasification for electricity generation in Cambodia in December 2014. The potential for rice husk is 2 million tons in December 2014. This potential from their study generate an equivalent of 1100 GWh of electricity. The work just considered only the potential of electricity generation from rice husk, gasifier design and rural electrification was not part of the program. Asadullah et al [25] studied the gasification of rice husk and other biomass by using a dual-bed gasifier coupled with $Rh/CeO_2/SiO_2$ catalyst. Only the study of gasification of rice husk was done without the gasifier design, no secondary filtration of producer gas and any traditional rural electrification was done. Md. Risat and Himadry [26] studied a potential way to bring electricity to rural Bangladesh using rice husk gasification technique. Four villages, Dinajpur, Ishawrdi, Bogra and Naogaon were used to ascertain the availability of rice husk in the area. Their findings show a total of 455.35 million tonnes per year of rice husk production in the four study area with a potential of 29050 kW/hour power generation. Although the work considered only the potential of electricity generation from rice husk, gasifier design and rural electrification was not in the work schedule. It can be seen that electricity generation from rice husk has been done for developing countries. Moreover, most of these studies centred on potential of electricity generation using rice husk and do not take into account rural electrification. The design and analysis of the gasification system for secondary filtration of the producer gas was not done. The cyclones and gas scrubbers are used for producer gas secondary filtration. Most of the gasifier presented is fluidised bed gasifier which can increase the formation of contaminant of hydrogen sulphide, carbon iv oxide and ammonia when moist rice husk is used as input fuel; thus, leading to clog of gasifier and the gas engine. This can be overcome by the use of down draft gasifier. These issues are considered in the present study, thereby bridging the knowledge gap.

3.0 Methodology

This study used analytical approach to determine the electrical load demand, energy demand, resource assessment and potential of electricity generation of the study area (Adani in Uzo-Uwani L.G.A of Enugu state, Nigeria). Rice husk chemical mass balanced and energy balance were used to design the gasifier system and Autodesk Inventor Professional 2015 was used to produce the design. A detailed load assessment and resource availability of the study were presented. Also, the detailed gasifier system design was done. The block diagram of the design is as shown in Figure 1.

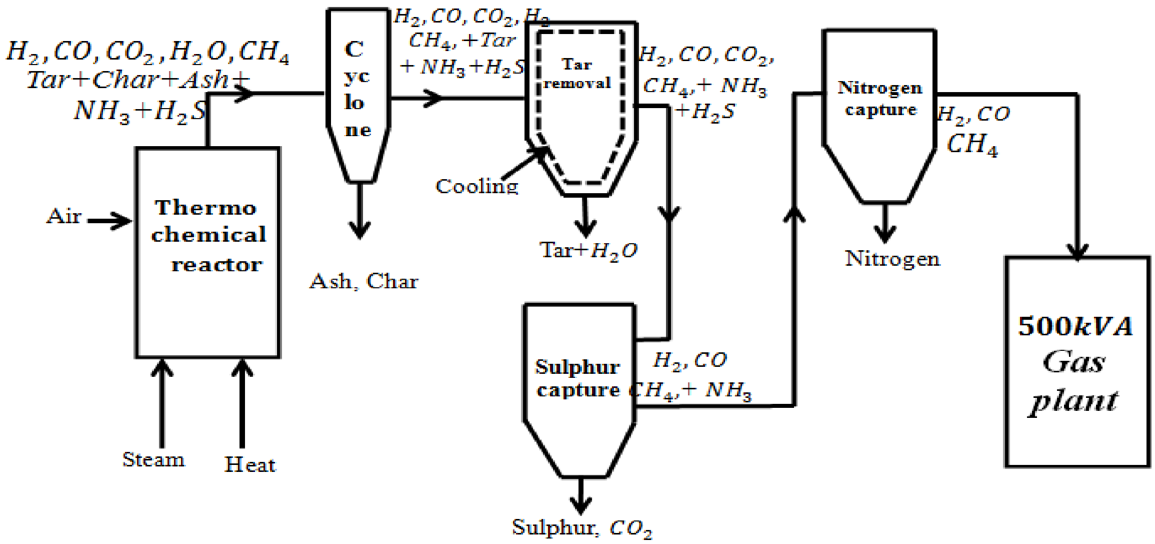

Figure 1: Block diagram of rice husk gasification for electricity generation.

3.1 Estimation of Energy demand of Adani

The purpose of the energy demand estimation is to know the daily, monthly and yearly energy demand of Adani. This information helped us to know if the resource for power generation in the location is sufficient to satisfy the energy demand of the study area. The selected location for this study is Adani, in Uzo-Uwani L.G.A of Enugu state, Nigeria. The details of the location are listed in Table 1. Adani is bounded to the north by Nsukka L.G.A, to the east by Udi L.G.A. and to the south by Ayamelum L.G.A in Anambra state. The nearest urban centre is Nsukka, which is about 15 - 20 km away from Adani.

Table 1: Details of Adani [27]

S/N	Particulars	Details
1	Name of study area	Adani
2	L.G.A.	Uzo-Uwani
3	State	Enugu
4	Country	Nigeria
5	Latitude	6°55^I N and 7° 15^I N
6	Longitude	6° 30^I E and 7° 00^I E
7	Grid electricity	Yes
8	Number of households	1,500
9	Number of shops	350
10	Rice mills	36
11	Cassava processing machines	7
12	Palm processing machines	5

13	Police station	1
14	Banks	1
15	Schools (Primary and Secondary schools)	14
16	Hospitals	5
17	Churches	10

During the estimation of electricity demand of Adani, the electrical loads of 20 shops, 20 households, 4 rice mills, 2 cassava processing machines, 2 palm oil processing machines, 3 hospitals, 3 churches, 5 schools, 1 bank and 1 police station were used to determine the average energy demand of each load category. The load type, power rating of the load, quantity of the load and hours in use per day were taken. For ease of analysis, the electricity demand was grouped into four categories: domestic purposes, industrial/commercial purposes, school/religion purpose and health purpose as shown in Table 2. Electrical loads of shops, rice mills, cassava processing mills, palm oil processing mills, bank and police station were categorized as industrial/commercial purposes loads.

Table 2: Estimation of Energy demand of Adani

S/N	Particulars	Unit demand	Qty used	Total qty	Total demand
1	**Domestic Purpose load and energy demand** Average load demand per household Average energy demand per household	457W 4,876Whr.	20	1500	685,500W 7,314,000Whr.
2	**Industrial/Commercial (Community purposes)** Average load demand per community purpose Average energy demand per community purpose	380W 3,961Whr.	30	400	152,000W 1,584,400Whr.
3	**School/religion purpose** Average load demand per school/religion purpose Average energy demand per school/religion purpose	336W 1,931Whr.	6	24	8,064W 46,344Whr.
4	**Health purpose** Average load demand per health purpose Average energy demand per health purpose	898W 9294Whr.	3	5	4,490W 46,470Whr.
5	**Total Energy demand of Adani** Total load Daily energy demand Monthly energy demand Yearly energy demand				**850.054kW** **8,991kWhr.** **269.7MWhr.** **3,236.8MWhr.**

From Table 2, the total electrical load of Adani is 850.054kW; with total daily, month and yearly energy demands of 8,991kWhr, 269.7MWhr and 3,236.8MWhr respectively. The load assessment was done in excel worksheet, using customized data templates for this purpose.

3.2 Resource assessment

The purpose of the resource assessment is to know if the availability of rice husk in the study area has power potential to cater for the total load of the area. The availability of rice husk in Adani was assessed using the 36 rice mills in the location. The rice mills were named M1, M2, M3, - M36. The daily production of rice husk in each rice mill was gathered and measured in per week basis (every Saturday) in each rice mill using a weighing balance. The measurement was done for a period of 12 months (from November 2018 to October

2019). The availability of rice husk in each of the mills from November, 2018 to October, 2019 is as shown in Table 3.

Tables 3: Annual availability of rice husk in Adani

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice husk Availability (Tons)	217.65	164.6	108.25	294.45	212	180	196	300	420	510	399.06	674.25
Total	3,636 *tonnes per* annum.											

3.3 Mathematical modelling of rice husk power plant

In the case of rice husk gasifier system, the annual output energy, E_{bg} , of the rated rice husk gasifier system (P_{bg}) depends upon the capacity utilisation factor and was calculated using,

$$E_{bg} = P_{bg} \times 8760 \quad (1)$$

Putting the Capacity Utilization Factor (CUF) of the plant into consideration, the annual energy output is:

$$E_{bg} = P_{bg}(8760 \times CUF) \quad (2)$$

Where: E_{bg} is annual output energy in Whr or kWhr or MWhr or GWhr. ; P_{bg} is the rated biomass gasifier power in Whr or kWhr or MWhr or GWhr; CUF is the Capacity Utilization Factor. The power rating of the rice husk gasifier was calculated using,

$$P_{bg} = \frac{M_{bg} \times 1000 \times CV_{bm} \times \eta_{bg}}{365 \times 3600 \times t_{bg}} \quad (3)$$

Where:

M_{bg} is the total biomass (Tons/yr.) available for power generation.

η_{bg} is the efficiency of the biomass gasifier system.

t_{bg} is the number of operating hour of biomass gasifier system in a day.

CV_{bm} is the calorific value of the biomass available.

The potential power capacity of Adani was calculated using Equation (4).

$$S_{bg} = \frac{P_{bg}}{Cos\theta} \quad (4)$$

Where:

S_{bg} is the potential power capacity of the rice husk gasifier system in MVA,

P_{bg} is the potential real power of the rice husk gasifier system in MW

$Cos\theta$ is the power factor of the generator, 0.8 was assumed for power factor in this design.

3.4 Rice husk power gasification design

The potential power capacity of Adani using the available rice husk is $S_{bg} = 2MVA$. It is not advisable to design $1 \times 2MVA$ power capacity. This is because once it breaks down; the whole customers will be out of supply. In addition to this, the generators will not be economically dispatched. Therefore, the total capacity was divided into four units, that is $S_{bg} = 4 \times 500kVA$. One of the 500kVA gasifier plants was designed, and it was scaled to four units. The block diagram of the design is as shown in Figure 1. Before the components design was carried out, the rice husk chemical mass and energy balance of the system was done; this helped to quantify the components design.

3.4.1 The system mass balance

The mass balance in this design has three purposes which are to;

i. determine the volume of producer gas in a given quantity of rice;

ii. get the amount of air required to completely oxidize the given quantity of rice husk;
iii. know the amount of steam required to completely decompose the given quantity of rice husk.

Table 4 shows the characterization of rice husk used for this design.

Table 4: Characterization of rice husk

S/N	Components analysis of rice husk		Average components of producer gas	
1	Carbon (C)	51.2%	Carbon monoxide (CO)	21%
2	Hydrogen (H)	5%	Carbon dioxide (CO_2)	10%
3	Oxygen (O)	36%	Methane (CH_4)	2.5%
4	Nitrogen (N)	0.7%	Nitrogen (N_2)	52%
5	Sulphur (S)	-	Water vapour (H_2O)	1%
6	Moisture	3%	Hydrogen gas	13.5%
7	Ash	5.1%		

In mass balance, mass input is equal to mass output. To calculate the volume of producer gas, the carbon balance of the system was done. In this system mass balance, 1kg of rice husk was taken as the basis. Let the producer gas in the system be Ykg-mole.

Then,

$$C\ in\ rice\ husk = C\ in\ producer\ gas + C\ in\ ash + C\ in\ tar \quad (5)$$

Where C is carbon

Doing the carbon balance of the system, carbon input is equal to carbon output, then:

$$C\ in\ producer\ gas = (C\ in\ CO_2 + C\ in\ CO + C\ in\ CH_4)Y + C\ in\ ash + C\ in\ tar \quad (6)$$

$0.043 = (0.1 + 0.21 + 0.025)Y + 0.029 = 0.335Y + 0.029,\ Y = 0.042\ kg - mole$

Therefore, the producer gas in 1kg of rice husk is $Y = 0.042\ kg - mole$. Applying gas law, noting the Standard Temperature and Pressure (STP) conditions, the volume of the producer gas is in 1kg of rice husk is $1.056m^3$. Removing the percentage impurities – nitrogen, water vapour and carbon dioxide (63%) from the producer gas, yields:

$V_p = 1.056 - \left(\frac{1.056\times 63}{100}\right) = 0.3907m^3$. Then, $V_p = 0.3907m^3$; this implies that the volume of the pure producer gas in 1kg of rice husk is $V_p = 0.3907m^3$

The next task is to determine the amount of air that will completely oxidize 1kg of rice husk using moist air as source of the oxidant with relative humidity of 80%, at atmospheric pressure of 740mmHg and partial pressure of steam is $P_s^{H_2O} = 26mmHg\ at\ 25°C$.

Nitrogen balance was done to get the amount of air required.

$$N_2\ in\ rice\ husk + N_2\ in\ moist\ air = N_2\ in\ producer\ gas \quad (7)$$

Substituting into Equation (7) yields:

$$0.00025 + 0.7677X = 0.022 \equiv 0.7677X = 0.02175 \quad (8)$$

From where $X = 0.028\ kg - mole$

Applying gas law and noting STP conditions, the volume of air required to oxidize 1kg of rice husk is $0.712m^3$. To determine the amount of steam that is required to decompose 1kg of rice husk, hydrogen balance of the system was done. Let Z kg-mole be the steam required to decompose 1kg of rice husk. Doing hydrogen balance gives:

$$H\ in\ RH + H\ in\ moist\ RH + H\ from\ steam + H\ in\ moist\ air = H\ in\ producer\ gas \quad (9)$$

Where H is hydrogen and RH is rice husk. Therefore,

$0.025 + 0.0017 + Z + 0.00084 = (0.025 + 0.135 + 0.01) \times 0.044)$, that is,

$0.02754 + Z = 0.00748$; Hence, $Z = 0.02\ kg - mole$. Applying gas law and noting STP condition, the volume of air required to oxidize 1kg of rice husk is $0.504m^3$.

3.4.2 The system Energy balance

The aim of energy balance is to determine the amount of energy required for the rice husk gasification. The energy can be introduced as work (W) or heat (Q), that is:

$E = Q + W$ (10)

Where: "E" is the energy; "Q" is the heat and "W" is work done

But

$W = P\Delta V$ (11)

The thermochemical reaction of the system takes place at constant volume; therefore,

$\Delta V = 0$ (12)

Substituting (12) into (11), we obtain; $W = 0$ (13)

Putting (13) into (10), gives: $E = Q$, Let the amount of energy required for the rice husk gasification be E_{in}. So that $E_{in} = E_{RH} + E_a + E_s$ (14)

Where:

E_{RH} is amount of energy required to completed oxidize a fixed volume of rice husk.

E_a is the enthalpy of moist air. E_s is the enthalpy of steam. Using Dulong's formula for biomass, $E_{RH} = G_{CV} - Heat\ of\ vaporation\ of\ water$ (15)

But: $G_{CV} = 81\%\ carbon + 341(\%Hydrogen - \%\left(\frac{Oxygen}{8}\right)$ (16)

$Heat\ of\ vaporation\ of\ water = 5.84\ (9\%\ H + 1.7\%\ of\ water\ in\ rice\ husk)$ (17)

Substituting into (15) gives: $E_{RH} = 4{,}217.7 - 292.584 = 3{,}925.116\ Kcal.$

Therefore, the amount of energy required to completed oxidize a fixed volume of rice husk is $3{,}925.116\ Kcal$. The enthalpy of moist air was calculated as:

$E_a = h_a + Xh_w$ (18)

Where h_a is the specific enthalpy of dry air. h_w is the specific enthalpy of water vapour.

X is mass of water vapour

$h_a = C_{pa} \times T$ (19)

C_{pa} is the heat capacity of air and T is the operational temperature.

$h_w = C_{pw}T + h_{we}$ (20)

C_{pw} is the heat capacity of water and h_{we} is evaporation heat of water.

Substituting into (18), gives: $E_a = \left[C_{pa} \times T\right] + X\left[C_{pw}T + h_{we}\right]$ (21)

Using steam table at 25^{0}C, $h_{we} = 2501\ KJ/kg$, $C_{pa} = 1.006\ KJ/kg$℃, $C_{pw} = 1.84\ KJ/kg$℃, $X = 0.02\ kg$. Then,

$E_a = [1.006 \times 25] + 0.02[1.84 \times 25 + 2501] = 25.15 + 50.94 = 76.09\ Kcal.$

Therefore, the enthalpy of moist air is $76.09\ Kcal$. The enthalpy of steam was calculated as:

$E_s = E_{25℃-100℃} + E_{100℃-100℃} + E_{100℃-700℃}$ (22)

Where $E_{25℃-100℃}$ is the heat required to raise temperature from 25^{0}C to 100^{0}C.

$E_{100℃-100℃}$ is the heat required to convert water at 100^{0}C to 100^{0}C steam.

$E_{100℃-700℃}$ is the heat required to convert 100^{0}C steam to 700^{0}C.

The formula to calculate heat at these different temperatures is gives as:

$q = MC\Delta T$ (23)

Where M is the mass of steam = 15gram. C is the specific heat capacity of water = 4.18J/g^{0}C.

C_s is the specific heat capacity of steam = 2.09J/g^{0}C. H_v is heat of vaporization of water = 2257/g. ΔT is the change in temperature. $E_{25℃-100℃} = MC\Delta T = 15 \times 4.18(100 - 25) = 4702.5J$; $E_{100℃-100℃} = M\Delta H_v = 15 \times 2257 = 33855\ J$; $E_{100℃-700℃} = MC\Delta T = 15 \times 2.09(700 - 100) = 18{,}810\ J$; $E_s = 4702.5J + 33855\ J + 18{,}810\ J = 57{,}367.5\ J$

Therefore, the enthalpy of steam is $57{,}367.5\ J = 57.3675\ KJ = 13.71\ Kcal.$

Substituting into Equation (14), the energy input for complete oxidation of the rice husk is:
$E_{in} = 3{,}925.116 + 76.09 + 13.71 = 4{,}014.92\ Kcal.$

3.4.3 Gasifier thermochemical reactor design

Here, the following were determined: (a) the height of the oxidation and reduction zone of the reactor; (b) reactor diameter and height of the reactor.

(a) Height and diameter of the reactor's oxidation and reduction zone

From JMP Limited 500kVA gas generator datasheet, the generator consumes 118 m^3/hr of gas at full load. Then, $the\ amount\ of\ RH\ required\ \ by\ the\ generator\ at\ full\ load\ is\ \frac{118}{0.3907} = 302.02 kg/hr.$

$$Volume\ of\ oxidation\ and\ reduction\ zone = \frac{302}{128} = 2.3577 m^3$$

But, $Volume\ of\ oxidation\ and\ reduction\ zone = \pi r^2 h = 2.3577 m^3$ (24)

Where: $r\ is\ the\ radus\ of\ the\ reactor\ in\ m$;
$h\ is\ the\ height\ of\ the\ oxidation\ and\ reduction\ zone\ in\ m$.

Obtaining the diameter of the reactor helped in getting the radius of the reactor from where the height of the reduction and oxidation zone was evaluated. The diameter of the reactor was calculated using:

$$D_r = \left[\frac{1.27 \times FCR}{SGR}\right]^{0.5} \quad (25)$$

Where: $D_r\ is\ the\ reactor\ diameter\ in\ m$ and $FCR\ is\ the\ RH\ consumption\ rate\ in\ kg/hr,$ substituting into (25) gives: $D_r = \left[\frac{1.27 \times 302}{160}\right]^{0.5} = 1.548\ m.$ Then, the radius of the reactor is $R_r = \frac{D_r}{2} = \frac{1.548}{2} = 0.774\ m.$ Substituting into 25, the height of the oxidation and reduction zone was obtained as: $h = \frac{2.3577}{\pi r^2} = \frac{2.3577}{\pi \times 0.774^2} = 1.2527\ m$ .The area of the oxidation and reduction zone is $\pi \times 0.774^2 = 1.88 m^2$

(b) Reactor diameter and height of the thermochemical reactor

This refers to the total distance from the top to the bottom end of the reactor.

$$H = \frac{SGR \times T}{Average\ bulk\ density\ of\ RH} \quad (26)$$

T is the required time to totally gasify the RH inside the reactor.

$$T = \frac{Average\ bulk\ density\ of\ RH \times V_r}{FCR} \quad (27)$$

Substituting into equation (27), noting that the $average\ bulk\ density\ of\ RH\ is\ 128 kg/m^3$,we obtain: $T = \frac{128 \times 10}{302} = 4.24\ hr.$ Substituting into equation (26), the total height of the thermochemical reactor is: $H = \frac{160 \times 4.24}{128} = 5.296\ m$

3.4.4 Cyclone separator design

In this design, 1D3D cyclone was adopted in order to achieve higher collection efficiency. The "D" is the cyclone barrel diameter. The cyclone has the following properties: the cyclone diameter is D_c; the length of the barrel is $L_c = 1 \times D_c$, the length of the cone is $Z_c = 3 \times D_c$; the diameter of dust outlet is $J_c = \frac{D_c}{4}$; the diameter of the clean gas outlet is $D_e = \frac{D_c}{2}$ and the diameter of the dusty gas inlet is $H_c = \frac{D_c}{2}$.

This 1D3D cyclone has design velocity of $16\ ms^{-1} \pm 2\ ms^{-1}$. The task is to determine the dimensions of the cyclone parts. The cyclone design velocity and the system gas flow rate are the basis to size a cyclone. The diameter of the cyclone was obtained using Equation 28.

$$D_c = \sqrt{\frac{8Q}{V_i}} \quad (28)$$

Where:
Q is the gas flow rate in m^3/s and V_i is the inflow gas velocity in ms^{-1}.

$$Q = V_i \times A \quad (29)$$

Where A is the area of the gas outlet of the thermochemical reactor in m^2.

$$A = \frac{\pi d^2}{4} \quad (30)$$

3.4.5 Gas scrubbers design

There are many types of scrubbers for gas conditioning but in this design, Venturi scrubber with 3D0.5D cyclone separator was adopted because of its high gas collection and cleaning efficiencies. The throat velocity and cross-sectional area was estimated using a modified Bernoulli equation as shown in Equation (31):

$$V_t = \frac{Q_m}{A_t} \quad (31)$$

From Equation (31);V_t is the scrubber throat velocity in ms^{-1};
A_m is the scrubber throat cross-sectional area in m;Q_m is the gas flow rate in m^3/s.
The property of this scrubber is as follows:
The scrubber cyclone diameter is D_s; the length of the barrel is $L_s = 3 \times D_s$; the length of the cone is $Z_s = 0.5 \times D_s$; the diameter of dust outlet is $J_s = \frac{D_s}{4}$; the diameter of the clean gas outlet is $D_{es} = \frac{D_s}{2}$ and the diameter of the dusty gas inlet is $H_s = \frac{D_s}{2}$.
The throat cross-sectional area was calculated from the scrubber inlet and throat velocities as shown in Equation (32):

$$A_t = A_i \times \frac{V_t}{V_i} \quad (32)$$

A_t *and* A_i are areas of the throat and inlet of the scrubber respectively.
The inlet cross-sectional area was calculated using;

$$A_i = \frac{\pi d^2}{4} \quad (33)$$

From the scrubber cross-sectional area, the dimensions of the throat of the scrubber was estimated. The diameter of the throat was found using Equation 34.

$$d_t = \sqrt{\frac{4 \times A_t}{\pi}} \quad (34)$$

The length of the scrubber throat is related to its diameter as:

$$l_t = 3 \times d_t$$

The length of the diverging section of the scrubber throat is related to its diameter as:

$$l_{div} = 4 \times d_t$$

The diameter of the cyclone part of the scrubber was estimated using Equation 35.

$$D_s = \sqrt{\frac{16Q}{V_i}} \quad (35)$$

3.4.6 Gas storage design

In this design, simple cyclone gas storage design was adopted. 3D0.5D cyclone was adopted for this gas storage, and the properties are:
The gas storage cyclone diameter is D_s; the length of the barrel is $L_s = 3 \times D_s$; the length of the cone is $Z_s = 0.5 \times D_s$; the diameter of the clean gas outlet is $D_{es} = \frac{D_s}{2}$; and the diameter of the pure gas inlet is $H_s = \frac{D_s}{2}$. The properties of the gas storage were obtained following the same way as that of the gas scrubber.

4.0 Results and discussion

This section presents the results of this research work. First, result of the electrical load and energy demands of the study area were presented, which is followed by the resource assessment result. The outcomes of the detailed design of the rice husk gasification system with secondary filtration were presented and the loading of the generators was also considered.

4.1 Electrical load and energy demand results

In this study, the total electrical load, daily, monthly and yearly energy demand of Adani was carefully estimated using onsite study. During the onsite study, the electrical load of Adani was grouped into four categories: household purpose electrical load, industrial/commercial purpose load, school/religion purpose load and health care purpose load. As shown in Fig. 2, the household purpose load is 686kW, industrial/commercial purpose load is 152kW, school/religion purpose load is 8.1kW and health care purpose load is 4.5kW. The total electrical load of Adani is the summation of the individual purpose loads, which is 850.005kW. Fig. 3 shows the daily energy demand of each of the categories of the load demand. The daily energy demand of household purpose, industrial/commercial purpose, school/religion purpose and health care purpose are: 7314kWhr, 1584.4kWhr, 46.344kWhr and 46.46kWhr respectively.

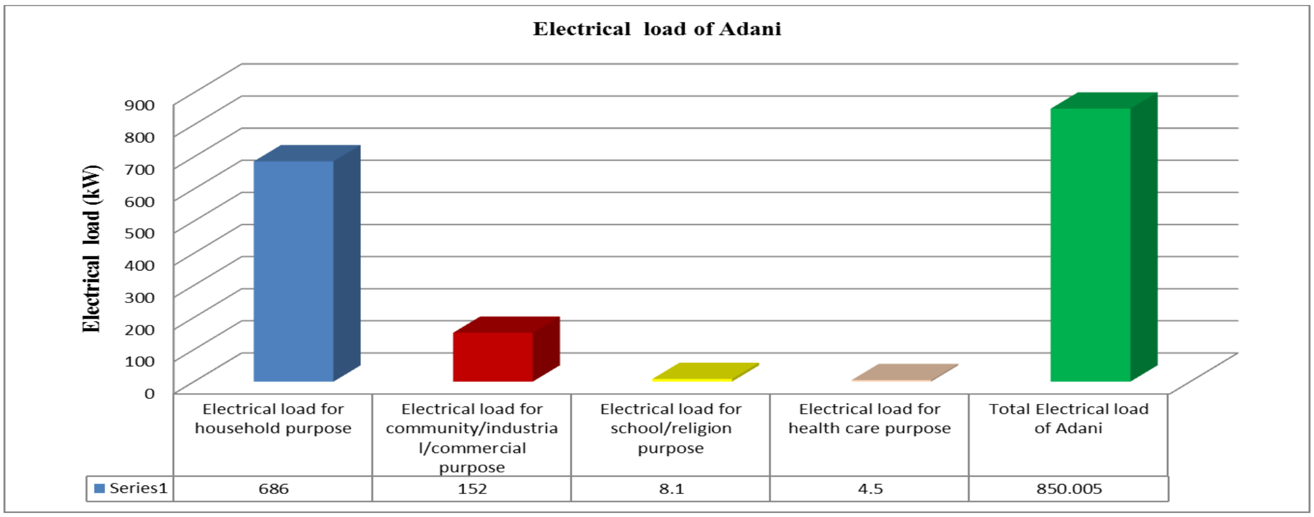

Figure 2: Electrical load of Adani.

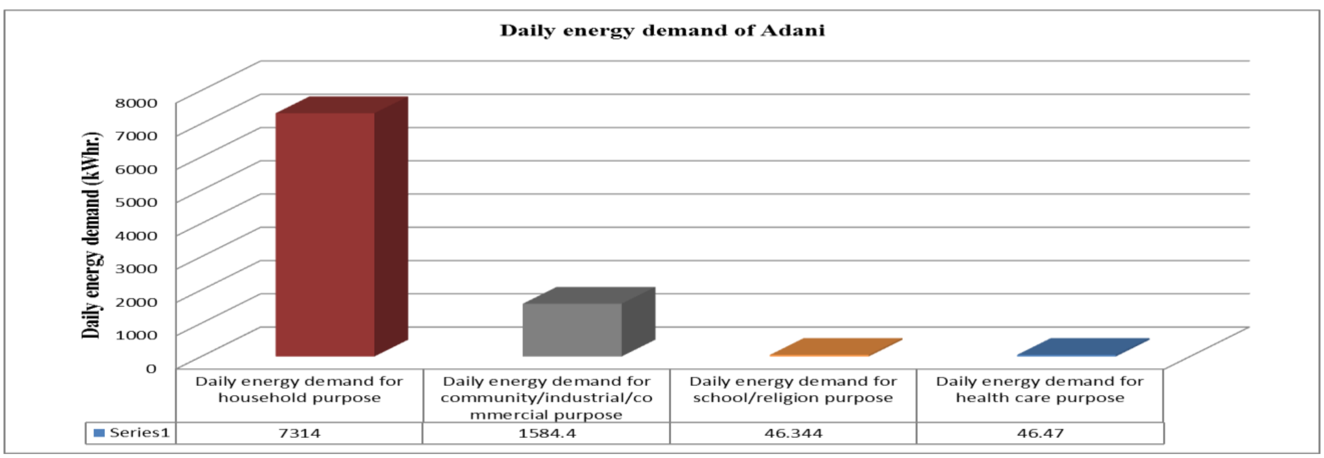

Figure 3: Daily energy demand of Adani.

The total daily, monthly and yearly energy demand of Adani as shown in Fig. 4 are: 8991kWhr, 269736.42kWhr and 3236837.04kWhr respectively.

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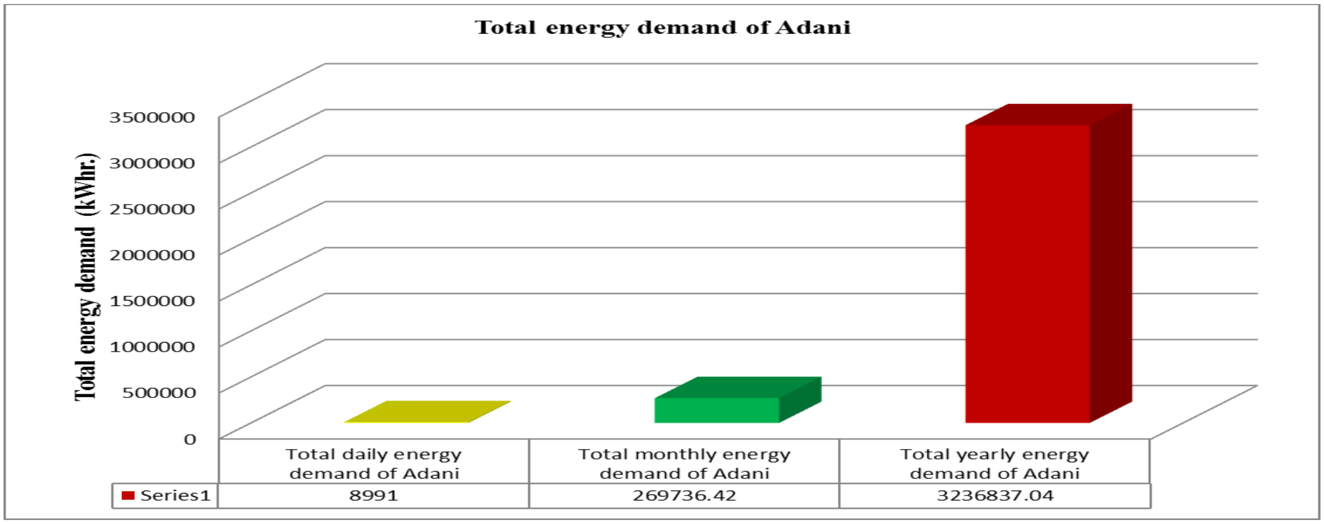

Figure 4: Total energy demand of Adani.

4.2 Resource assessment/power potential results

The purpose of the resource assessment conducted in Adani is to confirm if the availability of rice husk for power generation in the location is sufficient to carter for the energy demand of the area. Fig. 5 shows the availability of rice husk in kilogram in Adani from November 2018 to October 2019. As seen in Figure 5, the availabilities of rice husk in kilogram from November 2018 to October 2019 are: 399,060kg, 674,250kg, 217,650kg, 164,600kg, 108,250kg, 294,450kg, 212,000kg, 180,000kg, 196,000kg, 300,000kg, 420,000kg and 510,000kg respectively. Summation of all the monthly availability of rice husk gave the annual availability of 3,636,000kg rice husk. Using rice husk gasification power model, this annual availability of rice husk has the potential of 1,520,534.247W of electricity generation. This potential of electricity generation has power station capacity of 1.9MVA which is approximately equal to 2MVA.

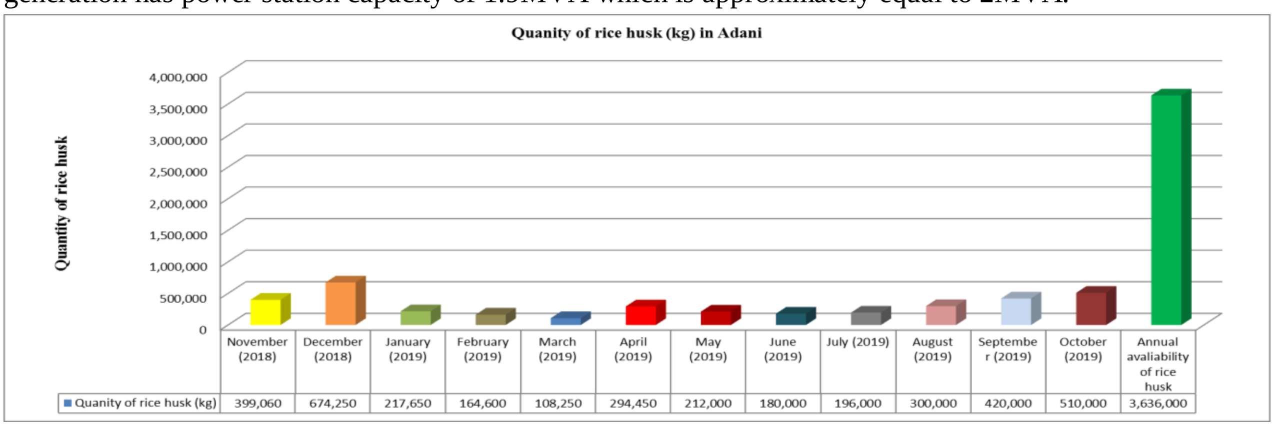

Figure 5: Shows the availability of rice husk in Adani.

Fig. 6 shows the comparison of estimated energy demand of Adani to the potential of electricity generation using rice husk in Adani. The estimated total daily, monthly and yearly energy demands of Adani are: 8991kWhr, 269736.42kWhr and 3236837.04kWhr respectively. While the total potential daily, monthly and yearly energy generation there are: 36.48MWhr, 1,094.4MWhr and 13,132.8MWhr respectively.

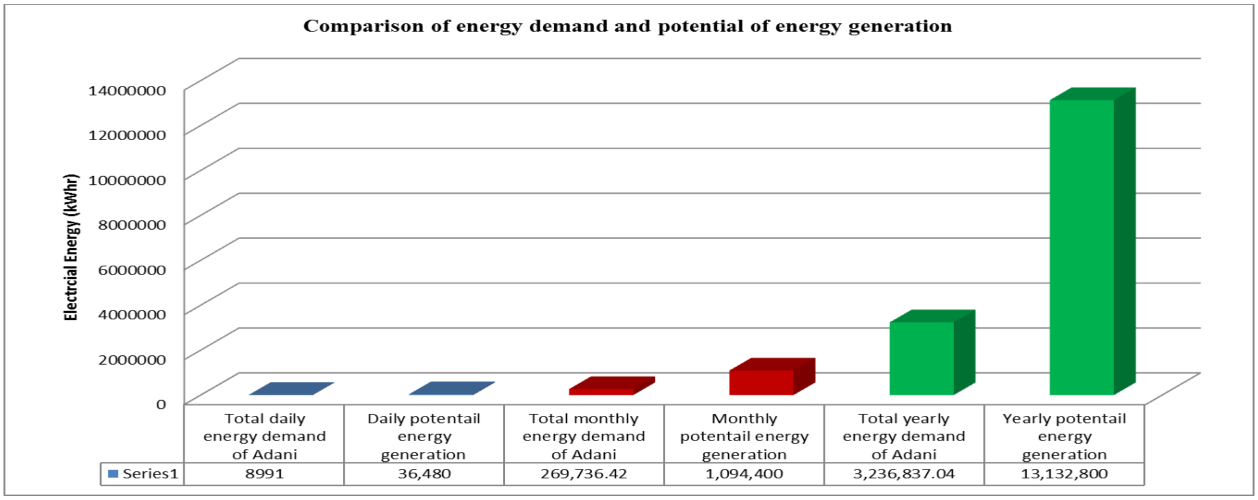

Figure 6: Comparison of estimated energy demand and potential energy generation.

It is obvious from Fig. 6, that the potential daily, monthly and yearly energy generation is higher than estimated total daily, monthly and yearly energy demands.

4.3 Overall Rice husk gasification design result. The various sectional results that gave rise to the overall result are briefly enumerated below.

4.3.1 Thermochemical reactor design result

Gasification of the rice husk takes place in the thermochemical reactor. From 500kVA Caterpillar gas generator datasheet obtained from JMP Limited Company, the generator consumes 118 m^3/hr of gas at full load. This information was used as the basis of the design. From the system mass balance, 1kg of rice husk contains $0.3907m^3$ volume of pure producer gas. The quantity of rice husk to produce 118 m^3/hr volume of pure producer gas (hydrogen, carbon monoxide and methane) at full load is: $302.02kg/hr$. The input energy required to generate this producer gas is 4,014.92 $Kcal$. This information was used to calculate the dimensions of the thermochemical reactor. The height of the oxidation and reduction zone of the thermochemical reactor is 1.2527 m, while the thermochemical reactor diameter is 1.548 m. The area of the oxidation and reduction zone is $1.88m^2$, the volume of the oxidation and reduction zone is $2.3577m^3$ and the height of the thermochemical reactor is 5.296 m.

4.3.2 Cyclone design result

The producer gas and impurities obtained from the gasification process are passed to the cyclone where some of the impurities like ashes are separated from the producer gas. In this design, 1D3D cyclone design connected in parallel in order to achieve higher collection efficiency was used. The Ds designation refers to the barrel diameter of the cyclone. From the design, the cyclone diameter is 0.25 m ; the length of the barrel is 0.25 m; the length of the cone is 0.75 m; the diameter of dust outlet is 0.0625 m; the diameter of the clean gas outlet is 0.125 m and the diameter of the dusty gas inlet is 0.125 m. To achieve high cyclone separation efficiency, the whole cyclone system was broken down into two smaller identical cyclones connected in parallel arrangement. This is to achieve increased gas velocity and centrifugal force of the cyclone, thus; increasing the separation efficiency. Doing that gave rise to two identical cyclones with the following dimensions: the cyclone diameter is 0.125 m ; the length of the barrel is 0.125 m; the length of the cone is 0.375 m; the diameter of dust outlet is 0.03125 m; the diameter of the clean gas outlet is 0.0625 m and the diameter of the dusty gas inlet is 0.0625 m.

4.3.3 Gas scrubber design result

In the design, the gas scrubber is to purify the producer gas by removing contaminant gases like sulphur, CO_2 and nitrogen. The design contains two identical gas scrubbers – one for nitrogen gas removal and the other for gas sweetening (sulphur and CO_2) removal. There are many types of scrubbers for gas conditioning but in this design, venturi gas scrubber with cyclone separator was adopted because of its high gas collection and cleaning efficiencies. First, the throat of the venturis gas scrubber was designed with the diameter, length and area of the throat being $0.112\ m, 0.336\ m\ and\ 0.009875m^2$ respectively. The length of the diverging section of the scrubber throat was determined as $0.448\ m$. The diameter of the cyclone part of the scrubber is $0.502m$. 3D0.5D cyclone was adopted for this scrubber and the following dimensions of the cyclone were obtained: the length of the barrel is $1.506\ m$; the length of the cone is $0.251m$; the diameter of dust outlet is $0.1255\ m$; the diameter of the clean gas outlet is $0.251m$ and the diameter of the dusty gas inlet is $0.251m$.

4.3.4 Gas storage design result

The gas storage is for storing the pure gas used for firing the generator. In the design, simple cyclone gas storage was adopted. The gas inlet cross-sectional area is $0.00395\ m^2$ and the diameter of the cyclone part of the scrubber is $0.251m$. 3D0.5D cyclone was adopted for this gas storage and the dimensions of the gas storage are: the gas storage cyclone diameter is $0.251m$; the length of the barrel is $0.754\ m$; the length of the cone is $0.126\ m$; the diameter of the clean gas outlet is $0.1255\ m$; and the diameter of the pure gas inlet is $0.1255m$.

4.4 The rice husk gasifier power system mode of operation.

Fig. 7 shows the designed rice husk power system components. The component labelled 1 is the water tank. The tank is to store water used for gas cooling and for forming aqueous solution with the gas sweetener. The component labelled 2 is the 500kVA generator. The generator is for the power generation (4 X 500kVA). The component labelled 3 is the purified gas storage cylinder. It is the source of gas input to the generator. The two components labelled 4 are the gas scrubbers. They are used for gas purification. The 6th component is the reactor climbing frame for the sole purpose of climbing the thermochemical reactor in order to refill rice husk feed stock. The 7th component is the steam/air generator for generating the oxidants – air and steam. Thermochemical reactor is the 8th component. That is where the gasification takes place. Fig. 8 shows the solid work of Figure 7. As shown in Figs. 7 and 8, when the rice feed stock of 302kg is poured into the thermochemical reactor, it occupies the height of the oxidation and reduction zone which is $1.2527m$. The area and volume of the thermochemical reactor this 302kg rice husk occupies are $1.88m^2$ and $2.3577m^3$ respectively. 0.1m above the oxidation and reduction zone is the ignition point of the thermochemical reactor for lighting up the oxidation and reduction zone. Upon igniting the oxidation and reduction zone, the oxidants - air and steam will be introduced to the thermochemical reactor intermediately and temperature within the thermochemical reactor will gradually rise to 700^0C. At is time, $H_2, CO, CO_2, H_2O, CH_4$, *tar, ash,* NH_3 *and* H_2S are produced and pass to the cyclone. The cyclone beats down the tar and ash while $\mathrm{H_2, CO, CO_2, H_2O, CH_4, NH_3}$ and $\mathrm{H_2S}$ flows to the first scrubber. This scrubber's function is to sweeten the gas by the removal of $\mathrm{CO_2}$ and $\mathrm{H_2S}$, while $\mathrm{H_2, CO, CH_4}$, and $\mathrm{NH_3}$ flows to the second scrubber where the $\mathrm{NH_3}$ is beaten down from the rest of the producer gases. The pure producer gas, $\mathrm{H_2, CO}$ and $\mathrm{CH_4}$, will be stored in the gas storage cylinder which will be used to fire the 500kVA generator.

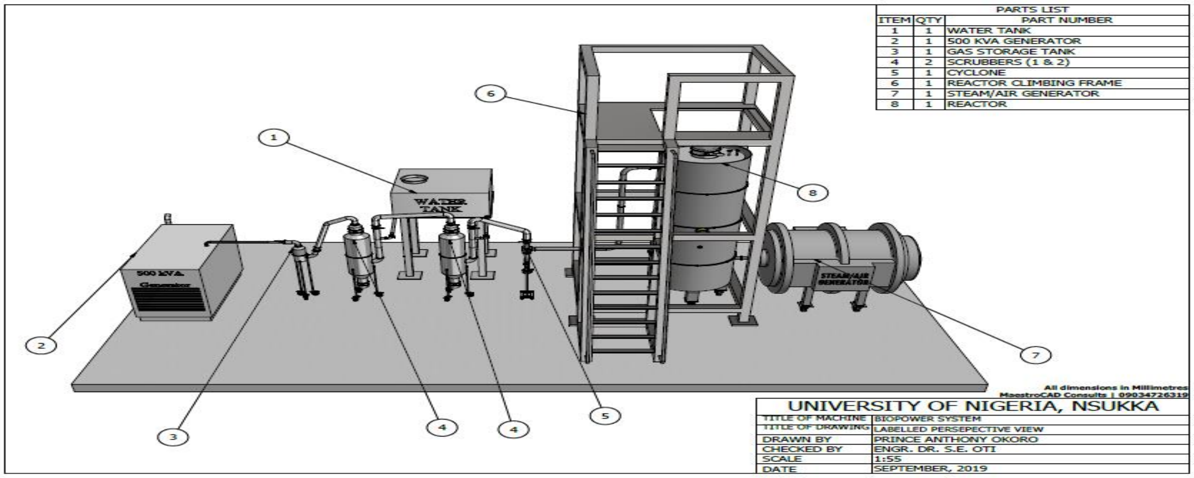

Figure 4.6: The rice husk power system components.

Figure 8: The solid work of the rice husk power system components

4.5 Power dispatch options for the study area.

Recall that the capacity of the generation station for the study area is 2MVA. This capacity was split into 4 X 500kVA. These four generators are identical. Since they are identical, the incremental full cost will be same. Two options were proposed for the power dispatch to the study area. The first option is loading the generators individually until the total demand of the study area is met. In this option, the house hold electrical load of 686kW was achieved by loading the first generator to full capacity of 400kW which is followed by loading the second generator to 286kW. The remaining electrical load to commit is the industrial/commercial purpose load, school/religion purpose load and healthcare purpose load which is altogether 165kW. This load was committed by loading the second generator to the full capacity, willing it's remaining 114kW power to industrial/commercial purpose load, school/religion purpose load and healthcare purpose load. Doing this, the remaining load to be committed is 165kW - 114kW = 51kW. This 51kW power was supplied by the third generator. The fourth generator acts as a spare/spinning reserve that caters for increment in electrical load demand or a spare generator when one of the committed three generators is undergoing maintenance. The second power dispatch option follows the processing of tieing the total generated power to a bus bar and distributes the power to the individual loads. In the case of the study area, the total electrical load demand is 850.054kW. The rating of the bus bar for this purpose is 3kA/415V. In this option, the three generators that met the electricity demand of the study area was committed and the power they produced was tied to the bus bar from which the power was dispatched to serve the total load of the study area. The fourth generator will be committed accordingly.

5. Conclusion

Nigeria is still looking for ways to achieve constant power supply in both rural and urban locations. Rice husk gasification technology for electricity generation presented in this paper is one of the ways to solve this issue as rice husks are available in high quantity in many locations of the country. The contribution of rice husk as a source of energy for electricity generation in rural and industrial locations can be significant if proper guidance and infrastructural help is available as evident in the case of the study area - Adani.

The estimated total electrical load of Adani is 850.005kW. The estimated total daily, monthly and yearly energy demands of Adani are: 8991kWhr, 269736.42kWhr and 3236837.04kWhr respectively. The annual availability of rice husk in Adani is 3,636,000kg/yr. Using rice husk gasification power model, this annual availability of rice husk has electrical power potential of 1,520,534.247W. The total potential daily, monthly and yearly energy generation from this annual availability of rice husk are: 36.48MWhr, 1,094.4MWhr and 13,132.8MWhr respectively. It is obvious that the potential daily, monthly and yearly energy generation is higher than estimated total daily, monthly and yearly energy demands. This potential of electricity generation has power station capacity of 1.9MVA which is approximately equal to 2MVA. This power generation capacity of Adani was used to design each components of the rice husk gasifier. The capacity was divided into four units in order to dispatch the generators economically that is $4 \times 500kVA$. One of the 500kVA gasifier was designed and was duplicated into four units. From 500kVA Caterpillar gas generator datasheet obtained from JMP Limited Company, the generator consumes $118\, m^3/hr$ of gas at full load. The quantity of rice husk to produce $118\, m^3/hr$ volume of gas at full load is: $302.02kg/hr$;

It is recommended that further work be done on off grid power supply option that can serve the whole of Uzo-uwani L.G.A. Such power option is hybrid power supply options.

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