Republic of the Philippines
OFFICE OF THE SECRETARY
Elliptical Road, Diliman
1100 Quezon City

MEMORANDUM ORDER
No. 01
Series of 2023

SUBJECT : ADOPTION OF TECHNICAL BULLETIN NO. 4 : DESIGN OF BIOMASS GASIFIER AS POWER SOURCE OF VARIOUS FARM MACHINERY AND EQUIPMENT

WHEREAS, in line with the implementation of the Renewable Energy Program for the Agriculture and Fisheries Sector (REPAFS), the use of cost-efficient renewable energy sources is being promoted for enhanced productivity, environmental protection, and sustainable development. Among these sources that has potential of becoming an alternative source of power for mechanization and infrastructure projects is the biomass, which is abundant in the agricultural sector.

WHEREAS, biomass gasifiers were locally developed in the country by Philippine Rice Research Institute (PhilRice) in the early 20's. Among the development undertaken by the PhilRice is the moving-bed downdraft-type gasifier which was successfully tested in providing fuel for both gasoline and diesel engines that drive pumps, chipping and chopping machines, fans, and other stationary farm equipment.

WHEREAS, as part of the promotional and capacity-building activities of the Department of Agriculture, the Bureau of Agricultural and Fisheries Engineering (BAFE) has conducted a Workshop on the Design, Installation, Operation, and Maintenance of Biomass Gasifier, in coordination with the PhilRice as the technology generator. As an output of the workshop, a Technical Bulletin was developed to provide reference to all concerned implementing offices on the preparation of a biomass gasifier's design and technical specifications.

NOW THEREFORE, to facilitate the technology transfer of the developed biomass gasifier, this Memorandum Order is hereby issued for the adoption of the Technical Bulletin on the Design of Biomass Gasifier as Power Source of Various Farm Machinery and Equipment, as attached herewith.

This Memorandum Order shall take effect immediately upon approval.

Done this 5th day of January 2023.

DOMINGO F. PANGANIBAN
Senior Undersecretary

Attached: a/s

DA-CO-OSEC-MO20230105-00001

TECHNICAL BULLETIN NO.

SERIES OF 2022

DESIGN OF BIOMASS GASIFIER AS POWER SOURCE OF VARIOUS FARM MACHINERY AND EQUIPMENT

BUREAU OF AGRICULTURAL AND FISHERIES ENGINEERING
ENGINEERING PLANS, DESIGNS, AND SPECIFICATION DIVISION

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TECHNICAL BULLETIN
No. 4
Series of 2022

SUBJECT: **TECHNICAL BULLETIN NO. 4: DESIGN OF BIOMASS GASIFIER AS POWER SOURCE OF VARIOUS FARM MACHINERY AND EQUIPMENT**

SECTION I. RATIONALE

As part of collaborative efforts to boost the country's energy and food security, the Department of Energy (DOE) and the Department of Agriculture (DA) signed a Memorandum of Agreement (MOA) on August 6, 2020 for the implementation of a Renewable Energy Program for the Agriculture and Fisheries Sector (REPAFS), where a program document was recently issued on March 1, 2022. The program aims to promote the use of cost-efficient renewable energy sources such as solar, wind, hydro, small-scale geothermal, and biomass for fuel and power generation for enhanced productivity, environmental protection, and sustainable development.

Biomass, a renewable energy source that has the potential of becoming an alternative to conventional energy sources since the Philippines has an abundant biomass resource that can be tapped to power agricultural operations. Gasification is a thermochemical process that converts waste biomass into a gaseous product and provides environment-friendly waste disposal. Through this process, it can produce combustible gas that can fuel internal combustion engines that power farm machinery.

Gasifier, as the principal component of the gasification process, provides a space for thermochemical processes to take place. Biomass gasifiers were locally developed in the country by Philippine Rice Research Institute (PhilRice) in the early 20's. Among the development undertaken by the PhilRice is the moving-bed downdraft-type gasifier which was successfully tested in providing fuel for both gasoline and diesel engines that drive pumps, chipping and chopping machines, fans, and other stationary equipment.

As part of the promotional and capacity-building activities of the Department of Agriculture, the Bureau of Agricultural and Fisheries Engineering (BAFE) has conducted the Workshop on the Design, Installation, Operation, and Maintenance of Biomass Gasifier on November 29-December 3, 2021, in coordination with the PhilRice as the technology generator. As an output of the workshop, this Technical Bulletin is prepared to provide guidelines to all concerned implementing offices on the preparation of a biomass gasifier's design and technical specifications.

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SECTION II. DEFINITION OF TERMS

The following terms shall apply to this Technical Bulletin:

Biomass Feedstock – refers to renewable organic material that comes from plants and animals.

Biomass Gasification – refers to a thermochemical process of converting solid biomass into combustible gas in an oxygen-starved environment.

Biomass Gasifier – refers to a thermochemical converting device that produces combustible gas from biomass.

Bulk Density – refers to the density of biomass in order to determine the volume to be contained in a reactor.

Char – a by-product of gasification.

Farmers' Cooperatives and Associations – a group of individuals who have undergone social preparation and duly registered by any recognized government agencies (i.e., SEC, DOLE, DAR, DA).

Heating Value – refers to the amount of heat energy that is available in biomass which will be useful in determining the size of the reactor.

Implementing Office (IO) – refers to the DA RFOs, bureaus, attached agencies and corporations, and other implementing units.

Producer Gas – gas produced during gasification that can be used as a fuel.

Reactor – refers to the component of gasifier in which biomass is partially burn to produce combustible gases.

Right-of-Way (ROW) – part or entirety of a property, site, or location, with defined physical boundaries, used or required by government infrastructure projects.

Site or Location – refers to the property or land on which the agri-fisheries infrastructure will be constructed.

SECTION III. SCOPE AND COVERAGE

This Technical Bulletin is limited to the design of a biomass gasifier including the considerations on site selection and material to be used during fabrication, regardless of the specific machinery and equipment to be powered. Guidelines on funding, implementation, testing, operation, and maintenance of the biomass gasifier should be referred to the corresponding existing issuances.

SECTION IV. OBJECTIVES

This Technical Bulletin aims to provide the DA implementing offices with a ready reference the during validation and design preparation of biomass gasifier. Specifically, the technical bulletin aims to provide the following:

1. Site selection criteria for the location of the technology;
2. Guided procedures in the calculation of design parameters; and
3. Recommendations on the materials of construction.

SECTION V. SITE SELECTION CRITERIA

Selecting an appropriate location for the installation of the biomass gasifier is significant to attain the optimum performance and efficiency of the system. In addition, it can help out in eliminating energy losses in transforming fuel in producing power. The following are some parameters for consideration during validation:

1. Proposed location for the installation of the biomass gasifier shall be near the machinery, equipment, or facility to be powered;
2. The source of biomass feedstock should preferably be located near the proposed site of installation where minimal to no logistics are required. In case the source of biomass feedstock will need to be hauled from another location, the design and cost estimate for the facility shall include provision of a hauling vehicle or operating costs for hauling.
3. Site should be distant from flooding.
4. Site should have an established shed and concrete floor.
5. Site should preferably have an electrical supply for lighting during the operation.
6. Site shall have an adequate water supply for cooling the system's gas conditioning.
7. Site should have an area for proper disposal of char and other by-products, and for stacking of biomass feedstock.

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SECTION VI. BIOMASS GASIFIER DESIGN CONSIDERATIONS

With the aim of developing an appropriate design of biomass gasifier to supply power for farm operations and as a result of the site validation conducted, design parameters for each component shall be identified.

Based on the characteristics of the site validated and the intended use of the biomass gasifier, the components of biomass gasifier shall be identified first. Listed below are some of the existing types and classifications of biomass gasifier per component.

A. GENERAL DESIGN CONSIDERATIONS AND COMPONENTS

1. TYPE OF BED

1.1 Fixed Bed

As shown in Figure 1, a fixed bed consists of cylindrical space for fuel feeding unit, an ash removal unit, and a gas exit. The loading of biomass feedstock and subsequent removal of char are done in batches. The fuel bed is held stationary as the gasification occurs. The gasifier is operated with high carbon conversion, long solid residence time, low gas velocity, and low ash.

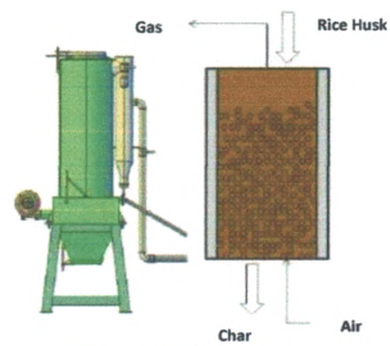

Figure 1. Fixed Bed

1.2 Moving-Bed

In a moving-bed gasifier (Figure 2), the biomass feedstock is gasified as it gradually moves down the reactor. The biomass feedstock is fed in the reactor as the char is discharged. This type of gasifier provides lesser power output due to its limited capacity. However, this system will provide continuous operation in comparison to a fixed-bed.

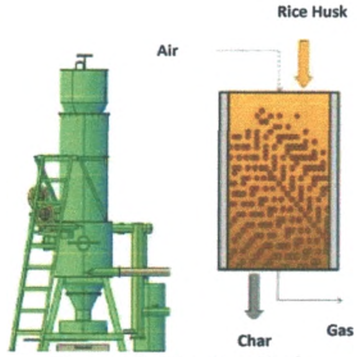

Figure 2. Moving-Bed

1.3 Fluidized Bed

In a fluidized-bed gasifier as shown in Figure 3, biomass feedstock moves in a stream manner inside a series of long reactors with inert gases where carbon monoxide and hydrogen are extracted. In designing a fluidized-bed gasifier, fuel feeding needs to be accurate and the reactor's temperature should be properly controlled. One of the major advantages is that the fuel flexibility that results from a proper mixing of feedstock and oxidant ensures efficient heat and mass transfer.

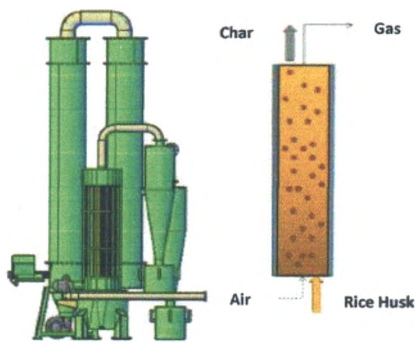

Figure 3. Fluidized Bed

2. Mode of Gasification

2.1 Downdraft

In a downdraft gasifier (Figure 4), biomass feedstock is fed from the top while air is passed downwards and is cocurrent in the direction of the fire zone. Furthermore, the producer gas leaves from the bottom of the gasifier. The oxidation zone is below the pyrolysis, and reduction zone is below the oxidation zone. One of the advantages for downdraft is that the producer gas is produced with low tar content that is suitable for gas engines. The gasification is suitable for moving-bed or continuous-type gasifiers.

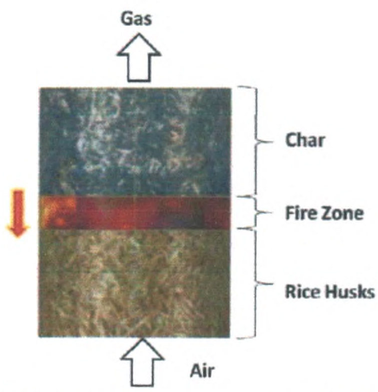

Figure 4. Downdraft Gasification

2.2 Updraft

In an updraft gasifier (Figure 5), biomass feedstock is fed from the top while air is passed upwards and is concurrent in the direction with the fire zone. In this system, the combustion zone is the lowermost portion of the gasifier where the char is formed due to drying. The system is simple to start and rapid continuous operation can be achieved. However, the gasification produces lots of tar and smoke during the operation. The gas produced in this mode requires thorough cleaning particularly when it is used as fuel for the internal combustion engine.

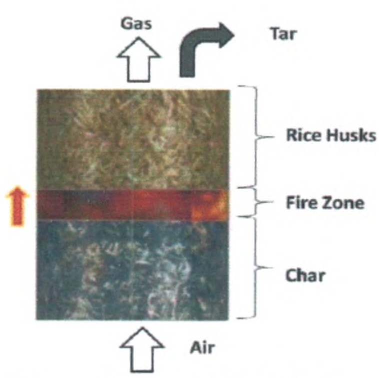

Figure 5. Updraft Gasification

2.3 Cross Draft

In cross draft gasification (Figure 6), air is introduced perpendicular with the movement in the fire zone. The producer gas is collected in the opposite side. However, the production in this mode is unpredictable when not enough char is produced in the bed. The char produced is a mixture of unburned biomass feedstock. The start-up time for the reactor is relatively short and high temperature is attained during this process.

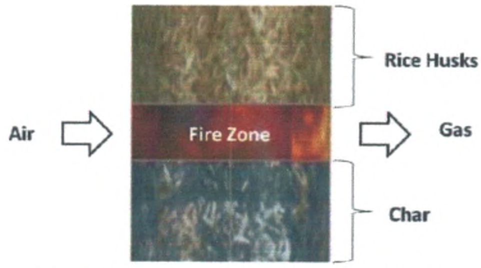

Figure 6. Cross Draft Gasification

3. Location of Fuel Ignition

3.1 Top Lit

The ignition is from the top of the reactor (Figure 7). This type of ignition is effective for downdraft-type gasifier since it will produce less tar and smoke during operation.

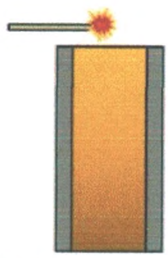

Figure 7. Top Lit Fuel Ignition

3.2 Bottom Lit

The ignition is from the bottom of the reactor (Figure 8). This type of ignition is effective for continuous-type moving-bed.

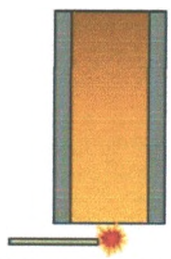

Figure 8. Bottom Lit Fuel Ignition

4. Mode of Operation

4.1 Batch Mode

Biomass feedstock is gasified in batch from the start of the operation until all the gas is completely extracted from the fuel. In batch mode, gas production is more stable than continuous mode. The operation time is limited since the char must be completely discharged from the reactor before restarting the operation.

4.2 Semi-Continuous Mode

Biomass feedstock is in sequence, thus making the operation longer due to two (2) or more reactors needed to be built for it to have a semi-continuous operation. Semi-continuous usually utilizes a fixed-bed type reactor which makes the operation more stable compared to continuous mode.

4.3 Continuous Mode

Biomass feedstock is fed into the reactor as char is discharged during operation. Accurate and synchronize feeding of biomass feedstock and discharging of char is necessary in order to achieve continuous operation and produce good gas quality.

B. GASIFIER COMPONENTS DESIGN CALCULATIONS

1. Engine Drive

Engine utilizes the gas produced from the gasifier after conditioning as fuel to produce the required power. The designer can choose either spark or compression ignition engine since both can use producer gas as fuel. Proper sizing of engine is required to properly meet the required amount of gas for a given displacement of the engine.

1.1 Type of Engine

1.1.1 Spark Ignition

The spark plug of the engine can ignite the fuel and use 100% of the gas.

1.1.2 Compression Ignition

The engine requires diesel for combustion and can be replaced by producer gas up to 90%. Thus, 10% is still needed to create combustion in the engine.

1.2 Engine Calculation

1.2.1 Design Power

After determining the required power load of the gasifier for the machine to be integrated in, the designed power can be calculated as shown in equation below. In addition, stationary machines such as pump, axial fan, blowers, conveyors, elevators, etc. shall be included with the conversion efficiency of 50%, whereas, for electricity generation is 30% in the parasitic power.

$$P_d = P_m + P_p$$

Whereas;

P_d = Design Power, hp
P_m = Machine Power, hp
P_p = Parasitic Power, hp

1.2.2 Engine Power

To calculate for the engine power required, with the use of designed power, the brake thermal efficiency of the engine and transmission efficiency should be first identified. The transmission efficiency is based on the engine type of drive, it can either be belt drive with 80-85% or direct drive with a 95-99% transmission efficiency. Furthermore, the brake thermal efficiency will depend on the type of the engine, for a spark ignition engine and compression ignition engine, the brake thermal efficiency will be 20-35% and 30-40%, respectively.

$$P_e = {}^{P_d}/_{(\xi bt\ x\ \xi t)}$$

Whereas;

P_e = Engine Power, hp
P_d = Design Power, hp
ξbt = Brake thermal efficiency, %/100
ξt = Transmission efficiency, %/100

1.2.3 Piston Displacement Rate

The piston displacement rate is needed to determine the amount of gas that will be used for the engine to provide the power needed on the integrated machinery. The equation below shows the calculation for the piston displacement rate for engine.

$$PDR = {}^{P_e}/_{HVG}$$

Whereas;

PDR = Engine piston displacement rate, m^3/hr
P_e = Engine Power, hp
P_d = Design Power, hp
HVG = Heating value of gas, $kcal/m^3$

1.2.4 Piston Displacement

The required piston displacement determines the suitable engine for the drive. The equation below will determine the needed piston displacement rate. It is recommended to select the higher size based on the computed piston displacement to compensate for additional power.

$$PD = {(2 \, x \, PD)}/{(N \, x \, \xi v)}$$

Whereas;

PD = Piston displacement, li
PDR = Engine piston displacement rate, m^3/hr
N = Engine speed, rpm
ξv = Volumetric Efficiency, %/100

2. Reactor

The reactor is the area where the biomass feedstock is converted to a combustible gas. The feeding of fuel is done from the top of the reactor through a hopper. The process inside the reactor is through a thermochemical reaction of carbon in the fuel with air, moisture, and gases inside the reactor. Air enters the reactor from the top and the gas produced exits from the inner reactor through the annular space between the inner and the outer cylinders with the use of a high-pressure blower that sucks the gas.

2.1 Number of Reactors

2.1.1 Single

Single reactor is suitable for both batch and continuous mode of operation. The component is easy to operate particularly for feeding fuel and discharging char. To accommodate the larger output for a single reactor, there is a need to design a bigger diameter for the reactor

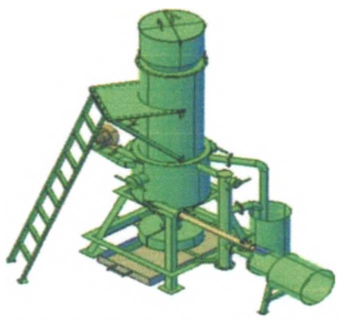

Figure 9. Single Reactor Gasifier

2.1.2 Multiple

In a multi-reactor system, the operation is done either in series or parallel depending on energy demand. For a batch-type system, the reactor is positioned in a semi-continuous operation while for a continuous system, the positioning of the reactors in parallel increases the power output of the gasifier.

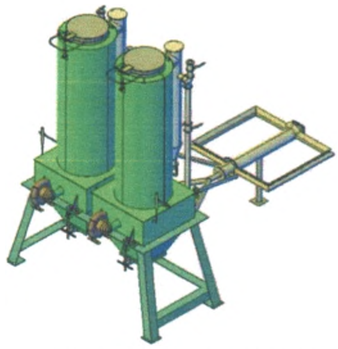

Figure 10. Multiple Reactor Gasifier

2.2 Reactor Calculation

2.2.1 Airflow Rate

To determine the amount of biomass feedstock needed to be gasified, the airflow rate as shown in the equation below shall be calculated and the gas-to-air ratio of 1.5 shall be considered with the gas flow rate using the piston displacement rate.

$$AFR = \left({}^{GFR}/_{GAR}\right) x\ \delta a$$

Whereas;

AFR = Airflow Rate, kg/hr
GFR = Gas to Fuel ratio
GAR = Gas to Air ratio
δa = Air Density, kg/m^3

2.2.2 Blower Flow Rate

In order to determine the needed volumetric flow for the blower to draw the air from the reactor and convert it into gas, the blower flow rate shall be considered.

$$BFR = {}^{AFR}/_{AD}$$

Whereas;

BFR = Blower Flow Rate, m^3/hr
AFR = Airflow Rate, kg/hr
AD = Air Density, kg/ m^3

2.2.3 Fuel Consumption Rate

In the determination of the needed volumetric flow for the blower to suck the air from the reactor and convert it into gas, the blower flow rate shall be considered. The equivalence ratio for the biomass gasification process ranges from 0.2 to 0.4.

$$FCR = {}^{AFR}/_{(SA\ x\ \epsilon)}$$

Whereas;

FCR = Fuel Consumption Rate, kg/hr
SA = Stoichiometric Air, kg_{air}/kg_{fuel}
ϵ = Equivalence Ratio, dmls

2.2.4 Reactor Inner Cylinder Diameter

The diameter of the gasifier reactor can be determined based on the calculated specific gasification rate. In order to determine the needed diameter, the designer can choose the type of grate to be considered. The following are the different types of grates to be selected from:

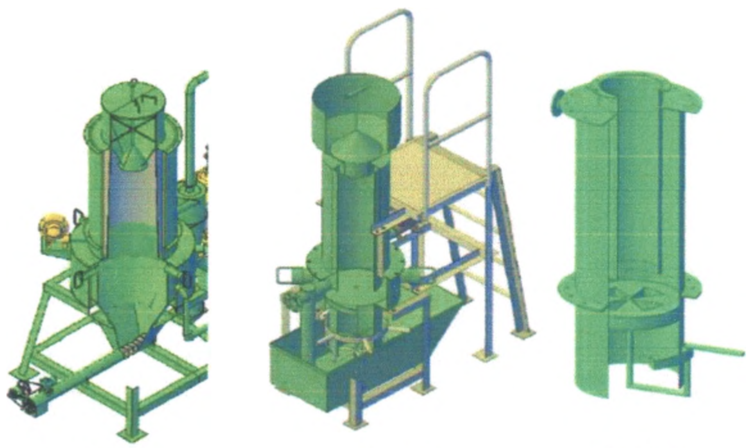

Figure 11. Types of Grates

After the selection of the grates, a specific gasification rate shall be considered. Specific gasification rate is defined as the amount of biomass fuel used per unit time per unit reactor area, the value can be ranged from 70 to 210 kg/hr-m2. The cross-sectional area for the reactor is calculated:

$$Ar = {}^{FCR}/_{SGR}$$

Whereas;

Ar = Reactor Cross-sectional Area, m^2
FCR = Fuel Consumption Rate, kg/hr
SGR = Specific Gasification Rate, kg/hr-m^2

Therefore, the diameter of the inner cylinder is calculated:

$$D_i = [1.27A_r]^{0.5}$$

Whereas;

D_i = Reactor Inner Diameter, m
Ar = Reactor Cross-sectional Area, m^2

2.2.5 Reactor Outer Cylinder Diameter

To assure that the char will not join with gas during the operation, the cross-sectional area of the outer cylinder must be equal to the cross-sectional area of the annular space between the inner and outer cylinder. To calculate the diameter of the outer cylinder:

$$D_o = 1.414D_i$$

Whereas;

D_o = Reactor Outer Diameter, m
D_i = Reactor Inner Diameter, m

2.2.6 Reactor Inner Cylinder Height

The height-to-diameter ratio of the reactor's inner cylinder is about 1:1-5 depending on the size of the reactor. The larger the reactor diameter, the lesser the ratio becomes. In addition, the thicker the reactor bed will result in a higher required pressure draft to move the air along the fuel bed.

$$H_r = HDR \; x \; D_i$$

Whereas;

H_r = Reactor Inner Cylinder Height, m
D_i = Reactor Inner Diameter, m
HDR = Height-to-Diameter Ratio

2.2.7 Cylinder Fuel Weight

To determine the weight of fuel to be placed inside the cylinder, the computed reactor diameter, height, and density of the biomass feedstock are needed.

$$W_f = A_r \; x \; H_r \; x \; \delta f$$

Whereas;

W_f = Fuel Weight, kg
A_r = Reactor Cross-sectional Area, m^2
H_r = Reactor Inner Cylinder Height, m
δf = Biomass Feedstock Density, kg/m^3

2.2.8 Fire Zone Rate

The rate of movement of the fire zone in order to determine its location during the operation of the gasifier is computed from the fuel consumption, density of fuel, and area of the reactor.

$$FZR = {}^{FCR}/_{(60\ x\ \delta f\ x\ A_r)}$$

Whereas;

FZR = Fuel Weight, kg
FCR = Fuel Consumption Rate, kg/hr
H_r = Reactor Inner Cylinder Height, m
δf = Biomass Feedstock Density, kg/m^3

2.2.9 Superficial Velocity of Gas at the Reactor

The superficial velocity at the reactor fuel bed is computed based on the airflow rate, and area of the reactor. This is used to check the occurrence of channel formation during operation.

$$SGV = {}^{AFR}/_{(3600\ x\ \delta a\ x\ A_r)}$$

Whereas;

SGV = Superficial Gas Velocity, cm/s
AFR = Airflow Rate, kg/hr
A_r = Reactor Cross-sectional area, m^2
δa = Air Density, kg/m^3

2.2.10 Required Static Pressure at the Reactor

The static pressure at the bed of biomass feedstocks used is generally 1 cm of water per m depth. In addition, 0.3 cm of water is added for the pressure draft exerted at the annular space between the inner and the outer cylinders to give maximum draft for the gasifier reactor.

$$SP_r = SSP\ x\ H_r$$

Whereas;

SP_r = Reactor Static Pressure, cm H_2O
SSP = Fuel Specific Static Pressure, cm H_2O/m
H_r = Reactor Inner Cylinder Height, m

2.2.11 Amount of Char Produced

The amount of char produced during the operation is determined by the fuel consumption rate and percent yield from char.

$$CDR = FCR \; x \; CY$$

Whereas;

CDR = Char Discharge Rate, kg/hr
FCR = Fuel Consumption Rate, kg/hr
CY = Char Yield, %/100

2.2.12 Char Discharging Capacity of the Grate

The function of the grate is to discharge the char produced at the reactor to sustain the continuous operation of the gasifier. If the reactor is filled with char, the loading of biomass feedstock will not be pushed in the reactor. To determine the char discharging capacity, the parameters needed to be determined are the reactor area, grate fuel depth, char density, and volumetric efficiency.

$$C_g = A_r \; x \; D_g \; x \; \delta c \; x \; \xi v$$

Whereas;

C_g = Char Discharge Rate, kg per sway
A_r = Reactor Cross-sectional area, m^2
D_g = Grate Fuel Depth, m
δc = Char Density, kg/m^3
ξv = Volumetric Efficiency, %/100

To determine the number of sways required per hour or the swaying frequency:

$$Number \; of \; Sways \; per \; hour = {}^{CDR}/_{Cg}$$

Whereas;

CDR = Char Discharge Rate, kg/hr
Cg = Char Discharge Rate, kg per sway

3. Gas Conditioning

Gas needs to be conditioned so that it can be suitable as fuel and to deliver minimal maintenance of the engine. Activities done during conditioning is the cleaning and cooling of the gas including tar since these products are corrosive and produce pollutants which may seriously interfere the burning of gas or the operation of the internal combustion engine. Table 1 shows the allowable amount of particulates in the gas stream.

Table 1. Allowable Amount of Particulates in the Gas Stream

Particulates	Allowable Amount
Dust	50 mg/m^3 and below, preferably 5 mg/m^3 of gas
Tar	500 mg/m^3 and below
Acids	50 mg/m^3 of gas and below

3.1 Methods of Gas Conditioning

3.1.1 Wet Method

Water is in contact with the gas during conditioning. This method immediately cleans and cools the gas, however, the heating value of the gas is reduced.

3.1.2 Dry Method

Gas is not in contact with water during gas conditioning. Immediate cooling cannot be achieved by requiring more effective heat exchange devices.

3.2 Devices for Gas Conditioning

3.2.1 Particle Separator

This device is used to separate char from the gas stream immediately from the reactor. This uses either a momentum separator or a cyclone separator.

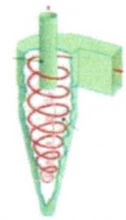

Figure 12. Particle Separator

3.2.2 Wet Scrubber

The function of the device is to remove tars/particulates from the gas stream by direct contact with water into the gas separating well the tar and reducing the temperature of the gas. There are three flows for wet scrubber; mainly (a) Concurrent flow, (b) Counterflow, and (c) Crossflow.

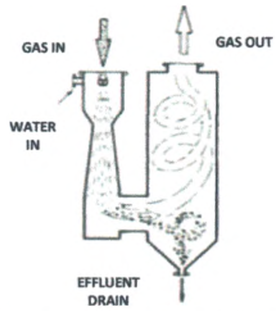

Figure 13. Wet Scrubber

3.2.3 Heat Exchanger

Heat exchanger is a device used to transfer heat or internal thermal energy between two or more fluids. In the heat exchanger, gas does not get in contact with water. Tars and particulates separate from the gas being cooled down as the gas moves from the inlet to the outlet of the scrubbing unit. It adopts either concurrent flow, counterflow, or crossflow heat exchanging method.

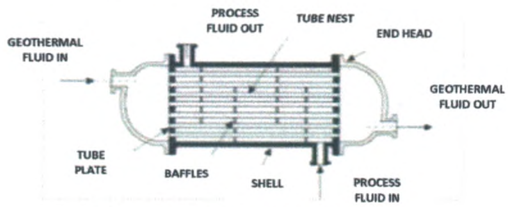

Figure 14. Heat Exchanger

3.2.4 Filter

This device is used to mechanically screen particles by allowing the gas to pass through a bed of small homogeneous materials. Filter materials can be crushed stones, pumice, cut tubes, fibers, fabric, etc.

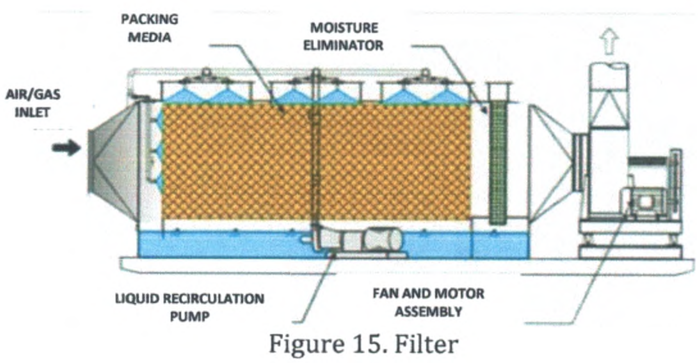

Figure 15. Filter

3.2.4.1 Types of Filter

3.2.4.1.1 Horizontal Packed-Bed Filter

This consists of solid granular materials such as biomass feedstock, wood chips, sand or pebbles, etc. It removes particles, dust, and tars as the gas passes through the spaces of the materials.

3.2.4.1.2 Vertical Packed-Bed Filter

Filter materials are oriented vertically in column. The design of the materials will be either circular or columnar for ease of replacement of the material.

3.2.4.1.3 Tube Filter

Filter material is made of cut tubes placed inside a barrel or pipe to effectively separate liquid particulates from the gas. The bed height is thicker than that in the packed bed filter.

3.2.4.1.4 Fabric Filter

Dust and particulates from gas is removed through a mechanical screening with the use of cloth or any suitable fabric material. This will be installed at the end of the series of filter device for final cleaning of the gas before feeding it into the intake manifold of the engine.

3.3 Calculation for Gas Conditioning

3.3.1 Gas Pipe Diameter

To calculate the diameter of gas pipe, the velocity of gas is needed to be considered. The velocity to be considered in the design must be more than 20 cm/s to prevent the char from getting stacked up in the pipe which may cause clogging and subsequently increase the pressure draft requirement of suction blower.

$$Dp = (1.27\ x\ {}^{GFR_p}/_{V_g})^{0.5}$$

Whereas;

A_p = Gas Pipe Area, m^2
GFR_p = Gas Flow Rate, m^3/hr
V_g = Design Gas Velocity, m/s

3.3.2 Heat Input to the Heat Exchanger

The gas entering the heat exchanger transmits a certain amount of heat that is necessary to cool down the gas temperature. The equation below shows the heat input to the pipe by the gas that enters the heat exchanger pipes.

$$Q_h = m_g \, x \, c_p \, (T_i - T_o)$$

Whereas;

Q_h = Heat Input to Heat Exchanger, kcal/hr
m_g = Mass Flow Rate, kg/hr
C_p = Specific Heat of Gas, kcal/kg
T_i = Inlet Temperature, °C
T_o = Outlet Temperature, °C

3.3.3 Area of Heat Exchanger Pipe

The total surface area of the heat exchanger pipe in order to drop the temperature of gas to a certain value is calculated using the heat input to the heat exchanger.

$$A_{he} = {Q_h} \Big/ \left(\frac{U((T_i - T_a) - (T_o - T_a))}{2} \right)$$

Whereas;

A_{he} = Surface Area of HE pipe, m²
Q_h = Heat Input to Heat Exchanger, kcal/hr
U = Overall Heat Transfer Coefficient, kcal/ m²- °C
T_i = Inlet Temperature, °C
T_o = Outlet Temperature, °C
T_a = Ambient Air Temperature, °C

3.3.4 Number of Heat Exchanger Pipes

In order to compute the surface area of each pipe, the determination of the pipe's diameter, schedule, and length are needed.

$$A_p = \pi D_p L_p$$

Whereas;

A_p = Surface Area of Pipe, m²
D_p = Diameter of pipe, m
L_p = Length of Pipe, m

If air cooling is needed for the heat exchanger, the number of pipes is determined by:

$$N_p = {A_{he}}/{A_p}$$

Whereas;

N_p = Number of Pipes
A_{he} = Surface Area of HE pipe, m^2
A_p = Surface Area of Pipe, m^2

3.3.5 Required Pressure Draft for Heat Exchanger

The pressure draft required for heat exchanger is not as much as compared to the filters. The specific draft ranges from 0.2 to 1.9 mm H_2O per m length of pipe. This can be computed by using the equation:

$$S_{ph} = SSP_p \, x \, L_p$$

Whereas;

S_{ph} = Pressure Head, cm of H_2O
SSP_p = Specific Static Pressure of Pipe, cm H_2O/m
L_p = Length of Pipe, m

3.3.6 Amount of Air Needed for Cooling of the Heat Exchanger Pipes

The amount of air needed to cool the heat exchanger pipes is computed using the heat and mass balance formula between the gas and the air in the cooling pipes.

$$M_a = {M_g C_{pg} \, (Tg_1 - Tg_2)}/{(C_{pa} \, (Ta_1 - Ta_2) x \, \xi he)}$$

Whereas;

M_a = Mass Flow of Air, kg/hr
M_g = Mass Flow of Gas, kg/hr
C_{pg} = Specific Heat of Gas, kcal/kg-°C
Tg_1 = Inlet Gas Temperature, °C
Tg_2 = Outlet Gas Temperature, °C
C_{pa} = Specific Heat of Air, kcal/kg- °C
Ta_1 = Inlet Air Temperature, °C
Ta_2 = Outlet Air Temperature, °C
ξhe = Heat Exchanger Efficiency, %/100

In order to get the volumetric flow of air in the heat exchanger pipes, the density of air will be needed.

$$VFR_a = {M_a}/{\delta a}$$

Whereas;

VFR_a = Volumetric Flow Rate of Air, m^3/hr
M_a = Mass Flow of Air, kg/hr
δa = Air Density, kg/m^3

After calculating the volumetric flow of air, the specification of the fan to be designed shall be higher than the computed air volume rate.

3.3.7 Cross-Sectional Area of the Filter

After choosing the suitable filter material for the gas conditioning unit, the cross-sectional area for filter will be calculated given the gas flow rate and filtration velocity.

$$A_f = {}^{GFR}/_{V_f}$$

Whereas;

A_f = Cross-sectional Area of Filter, m^2
GFR = Gas Flow Rate, m^3/hr
V_f = Design Filtration Velocity, m/s

In addition given the designed width, the height of the filter is calculated:

$$H_f = {}^{A_f}/_{W_f}$$

Whereas;

H_f = Height of filter, m
A_f = Cross-Sectional Area of Filter, m^2
W_f = Design Width of Filter, m

3.3.8 Required Pressure Draft for Filter

In order for the gas to pass through the filter bed, there is a required amount of draft pressure.

$$SP_f = SSP_f \; x \; t_f$$

Whereas;

SP_f = Pressure Head at Filter, cm H_2O
SSP_f = Specific Static Pressure of Filter, cm H_2O/m
t_f = Filter Thickness, m

3.3.9 Volumetric Flow Rate of Tar

The expected volume of tar to be collected is determined by the gas flow rate and the specific tar production.

$$VFR_t = GFR \ x \, STP$$

Whereas;

VFR_t = Volumetric Flow Rate of Tar, li/hr
GFR = Gas Flow Rate, m^3/hr
STP = Specific Tar Production, li/m^3

3.3.10 Total Gasifier Pressure

The total static pressure from the reactor, heat exchanger, and filter will be needed when specifying the pressure needed for the suction blower. The suction blower must be able to pull the gas at the computed gas flow rate and the total pressure of the gasifier.

$$TSP = SP_r + SP_{he} + SP_f$$

Whereas;

TSP = Total Static Pressure, cm H_2O
SP_r = Reactor Static Pressure, cm H_2O
SP_{he} = Heat Exchanger Static Pressure, cm H_2O
SP_f = Filter Static Pressure, cm H_2O

C. MATERIAL CONSIDERATIONS

Selecting the appropriate and suitable material is a vital step in order to ensure the quality, durability and strength of the materials to be constructed. In addition, to minimize the cost and improve the efficiency of the assembly, material testing is recommended in order to certify the structural integrity and quality of the assembly. For a gasifier, the materials are categorized to three different groups namely, fabrication, standard, and consumables.

1. Fabrication

Materials that will undergo production processes, this includes raw materials to make into specific forms and sizes. These materials will function accordingly to the designed parts. Table 2 shows the materials to be considered based on classification and parts of a biomass gasifier.

Table 2. Fabrication Materials Consideration

Classification	Part	Material
Sheet	Outer cylinders and casing	Black iron, boiler plate, stainless steel (minimum thickness 3-4 mm)
Plates	Inner cylinders, casing, flanges	Black iron, boiler plate, stainless steel (minimum thickness 5-8 mm)

Bars Medium Carbon High Carbon	Base frame, lateral frames, support structures, etc. Axles	Angle bar, flat bar, round bar, channel Cold rolled steel
Pipes	Gas pipe, heat exchanger, intake port, clean out, etc.	GI Pipe, stainless steel pipe, boiler tube pipe (minimum diameter 1.25 inches)

2. **Standard**

Materials that are readily available for use from the suppliers to perform a specific function, such as to fix machine parts, to transmit power, to move gases and liquid. Table 3 shows the materials for the parts and classification.

Table 3. Standard Materials Consideration

Classification	Component/s	Material
Assembly	Machine parts, flanges, etc.	Hexagonal bolts, nuts, and washer, blind rivets, self-tapping screws, set screw, etc. (should be non-corrosive)
Transmission	Suction blower, pumps, engine drive, etc.	Belts and pulley, chain and sprocket, couplers, universal joints, etc.
Gas	Reactor, wet scrubber, heat exchanger, filters, etc.	Ring blower, suction blower, and axial fan
Water Supply	Wet scrubber, heat exchanger, etc.	Peripheral pump, centrifugal, rotary pump, etc.
Power Drive	Engine	Spark or compression engine with single or multiple cylinder
Power Generation	Electricity generation	AC or DC generators, single or three phase

SECTION VII. IMPLEMENTATION PROCEDURES

For the implementation procedures, the IOs may refer to the issued Memorandum Order No. 50, Series of 2020 dated September 20, 2022 – "Revised Guidelines in the Provision of Agricultural Production, Postharvest and Processing Machinery, Equipment and Facilities".

SECTION VIII. OPERATION AND MAINTENANCE

This section includes all the pre-operation, operation, post-operation, and maintenance for its efficient performance and proper function of the system.

A. Pre-Operation

Before starting the operation of the system, it is essential to consider the following procedures:

- Check all the parts of the machine for possible loose bolts and nuts.
- Check the char bin, cooling bin, and safety pressure relief devices with water to the level as required. The height of water must be higher than the static pressure requirement of the gasifier components.
- Check and close all inlet and outlet ball valves to ensure that there is no possible leakage in the system.
- Check the gas pipe from the reactor to the engine to remove all possible sources of clogging and place sealant for connections and flanges to prevent gas/air leakages in the system.
- Reactor and the gas conditioning unit must be free from possible clogs and leakages.
- Assess if the suction blower for the reactor and the gas conditioning unit is in proper operating condition.
- Pump must be operational to circulate water to the scrubber or the fan that cools the heat exchanger.
- Ensure that the engine is functional and in good condition so that the gas can be burned properly to provide power to the pistons and crankshaft.
- For multi-cylinder engine, check the engine cooling system if there is an adequate supply of water at the cooling tank.
- Check the engine oil to ensure the right viscosity and level as required.
- Power transmission drive must be properly in place when driving machines.
- For cases of electric generator, it must be properly coupled to the engine drive and functional to provide the right electrical current and voltage to the electrical line.
- Check the battery condition for starting up the engine.
- Check the available supply of biomass feedstock fuel if it is enough for the intended operation. Biomass feedstock fuel be fresh and dry with at least moisture content of 14%. It is also advise to secure an extra supply of fuel away from the gasifier unit.
- Prepare the ignition torch for starting the reactor. Paper or kerosene can serve as an igniter for starting the gasifier.
- There should be sufficient amount of diesel or gasoline to start-up and for ending-off the operation of the system. For diesel engine, there must have enough fuel for its ignition which comprises about 10-30% of the total fuel.
- Check for the accessibility of the supply of water for cooling the gas conditioning unit and the engine. In some of the designs, there should be adequate supply of water for the char bin and for the water-cooling bin of the scrubber.

- Combustible material such as rags, woods etc. must be kept away from the system.
- For a small gasifier unit, check the availability of a metal bucket or container for the collection of char from the char bin to ensure its proper disposal.
- It is recommended that the gasifier to be operated in a well-ventilated area where the gas emitted from the reactor can be easily diluted with fresh air and the burnt gas from the engine are fully exhausted outside the power house.
- Avoid the use of dirty or wet biomass feedstock since it will produce poor-quality gas that hinders the performance of the system.
- For safety, fire extinguisher must always be kept in place in case of fire.

B. Operation

In order to optimize the benefits that can be derived from the technology, it is necessary to perform the right procedure in the operation of the system. The operation is quite complex at the start, however, through continuous operation, it becomes simple and easy to operate.

The following are the general procedure to be executed for proper operation of the system:

1. Fill the reactor with char up to the bottom end of the inner cylinder. For grateless-type reactor, more amount of char is needed to fill the space. In addition, ensure that the char layer leveled properly during the filling of char.
2. Fill the reactor with biomass feedstock at moisture content of 14% and below, up to 20 cm high to serve as start-up fuel. For larger diameter of reactor, it will require higher depth of biomass feedstock.
3. Start the engine to run the suction blower to suck the air and the gas from the reactor. In some other designs the use grid or battery as external power source for the blower, operate the blower first. It is recommended to set the engine speed at its optimum in order to obtain the right airflow and pressure that it required for the blower.
4. Lit the biomass feedstock fuel in the reactor by dropping burning crumpled pieces of paper until the biomass feedstock serving as igniter.
5. Ignite the gas coming out of the gas valve to determine if the it is already combustible or not. Once the blue flame is coming out of the valve, which is around 2 to 7 minutes from the start up, it can be attached to the gas feed port of the engine.
6. Control the amount of gas and air being fed into the engine until optimum engine is achieved. For spark-ignition engine, this can be completely replaced by the gas producer, whereas, for compression ignition, 10-30% of diesel is needed to be fed into the engine to create ignition.

7. Fill the reactor with biomass feedstock up to the topmost end. When the fire zone layer reaches the middle portion of the reactor, biomass feedstock is loaded into the reactor right after discharge of char.
8. For units with cooling pump and fan that use independent switches and valves, switch them to "On" to start the water or the ambient air to operate the scrubbers and/or the heat exchanger.
9. Start loading the engine by engaging the pulley to the machine to be driven. A clutch mechanism must be provided in the transmission drive to gradually drive the load.
10. Once the fire zone reaches the middle of the reactor, discharge the char from the reactor which can be done either manually or automatically to fed biomass feestocks fuel to make the reactor run continuously. Do not heavily discharge the char for it may disrupt the fire zone layer where the gas is produced. On the other hand, delay in the discharging the char may cause the fire zone to reach to the topmost end of the reactor which subsequently causes the operation to stop.
11. Reload the reactor with biomass feedstock fuel. The amount of biomass feedstocks fuel loaded into the reactor must coincide with the amount of char discharged. Maintain the fire zone layer at the middle of the reactor at all times to ensure that there is no interference during operation. For small or manually-operated discharging system, feeding of biomass feedstock at the top of the reactor. For larger system with bucket elevator, feeding of biomass feedstock fuel must be at the same rate as with the discharge of char.
12. Remove char from the char bin once in a while by operating the discharge screw manually or by means of motor. For manually-operated char scraper, carefully turn the lever to discharge the char directly onto a container. For units equipped with char bin that is positioned beneath the reactor, removal of char must be done gradually using a screen-equipped scoop and putting the char into a metal bucket for subsequent disposal. To maintain the required level of water in the bin, it is recommended to add water into the char bin from time to time.
13. Monitor the operation from time to time to check the unit's proper operation. It is an indicator that if there is an observed change in speed, the system should be checked immediately.
14. Before shutting off the operation of the gasifier, stop loading the reactor with biomass feedstock fuel. Allow all the biomass feedstock inside the reactor and those in the hopper be completely consumed before stopping the operation for it is not easy to remove biomass feedstock fuel when the operation is abruptly stopped. If the unit is equipped with bucket elevator, feed the remaining biomass feedstock fuel in it into the reactor and be allowed to completely burn before stopping the operation.

15. When no more combustible gas is produced in the reactor, continue the engine operation with gasoline or diesel as fuel. This would take 5 to 15 minutes, depending on the design of the gasifier, for residual tars, if there is any, to be burned at the intake manifold and combustion chamber of the engine.

C. Post-Operation

When the operation has ended, the following procedures shall be perform to ensure the safety of the system and the operator;

1. Reactor shall be cooled first before conducting post-operation activities.
2. Remaining char and biomass feedstock should be discharged in the reactor of the gasifier.
3. Ball valves should be open to discharge the tars and particulates that were entrapped in the scrubber, heat exchangers, and filters. It is also advisable to not leave them too long inside the machine components since it is difficult to remove once completely settled and solidified at the bottom.
4. Clean the components from dusts, residual biomass feedstock and char. In addition, make sure that all the components properly cooled down to prevent from causing accidental burning when touched.
5. Wipe the gasifier parts with dry rags or pressure blower from dust and other particulates.
6. Cover the electrical parts when cooling the gasifier. It is also recommended to not spray water on the inside of the reactor, especially when it is hot for it may easily corrode metal parts producing metal rust.
7. Check the damaged parts and immediately repair them to ensure that the machine will be operational.

D. Maintenance

In order to make sure that the system will prolong its useful life, proper maintenance should be considered. The following are recommended for the maintenance of the system:

1. General

- Components and parts of the machine should check before and after operation. The system should be cleaned and properly kept in dry condition. Also, there should be no residual biomass feedstock and/or char in any component of the gasifier before using it.

- Check for possible air/gas leakages at the fuel reactor and at the gas conditioning unit. If there is any gas leakages, this will needed to be fixed first before operating the gasifier. Parts of the system with holes should be welded or fixed.

2. Reactor

- The reactor should be checked for presence of corroded parts. For small gasifier unit, disassemble the different parts of the component to clean and check for corroded part. To replace the corroded part, weld the same material.
- Remove the char sticking onto surfaces between the inner and the outer cylinders of the reactor.
- Check the functionality of the grate whether or not it can properly discharge char during operation.

3. Scrubber

- The pipe of the scrubber should be cleansed during the maintenance period to remove tars and other particulates that stacked onto the surfaces of pipe.
- Sprays nozzles need to be free from clogs so that required pressure during scrubbing can still be obtained.
- Tars and other solid particles collected from the scrubber tank shall be washed off.
- Sodium Hydroxide solution shall be used for effective removing of tar and other difficult-to-remove substances adhering the surfaces of the system.
- To avoid corrosion of the parts of the engine, rinse with water and dry in a safe place.

4. Heat Exchanger

- Heat Exchanger is cleaned by filling the headers and the pipes with sodium hydroxide solution until the surfaces are free of tars.
- Rinse thoroughly with water after the solution is drained so the engine and gasifier will not be damaged.
- Inlet port and outlet must be checked from leakages since these may affect the operation of the gasifier.

5. Gas Filters

- Some of the designs only require back washing to remove entrapped residual tars and particulates with the use of sodium hydroxide at the top of the filter allowing it to drip off to the bottom followed by rinsing with water to remove impurities adhering the filter bottom while others require replacement from time to time.
- If the filter is made from fiber, it can be washed by soaking them in a solution for one hour before rinsing them with water.
- Check filters from possible leakages and dysfunctional ball valves.

6. Gas Pipe and Gas Fuel Feeder

- Tar needs to be removed so the suction blower can properly pull the gas from the reactor and convey it to the gas conditioning devices.
- Cleaning the gas pipes and the gas fuel feeder can be done by disassembling them from the gasifier assembly then placing them in a bin with sodium hydroxide solution for overnight.

SECTION IX. TESTING, COMMISSIONING, AND ACCEPTANCE

The testing and commissioning of the components of the facilities shall be undertaken by the suppliers, prior to the actual system testing to facilitate efficient testing.

Pursuant to Section 18 of RA No. 10601 also known as the Agricultural and Fisheries Mechanization (AFMech) Law, agricultural and fisheries machinery and equipment to be sold in the market shall pass through testing and evaluation by the Agricultural Machinery Testing and Evaluation Center (AMTEC) in accordance with the national policies and guidelines to be promulgated by the Secretary. Specifically, before it can be assembled, manufactured, and commercially sold in the market, the model of the machine and any modification thereof should be tested by the AMTEC and should pass the prescribed quality and performance standards.

Moreover, based on DA Memorandum Order No. 35, series of 2018, otherwise known as the Guidelines on AMTEC Testing and Evaluation of irrigation systems, processing facilities, and other agricultural systems of the DA, its RFOs, attached agencies, bureaus, and government-owned and controlled corporations, the following procedures should be observed:

1. The AMTEC testing and evaluation should be conducted after the complete installation of the machinery on site.
2. The AMTEC test report shall be submitted prior to the acceptance and payment of the procuring entity.

Moreover, based on DA Memorandum Order No. 50, series of 2020, an acceptance/compliance report shall be issued by the RAED and shall serve as basis on accepting the delivered goods/infrastructure.

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For information and guidance.

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Director IV

Attached: a/s

ANNEX A

Fuel Heating Value

Fuel	Heating Value (kcal/kg)
Bagasse	4,695
Coconut Coir	4,302
Coconut Shell	4,797
Corn Cob	3,705
Cotton Stalk	4,278
Peanut Hull	4,102
Rice Husk	3,000

ANNEX B

Thermochemical Properties of Rice Husk

Bulk Density	
Well Packed	128 kg/m^3
Loosely Packed	100 kg/m^3
Moisture Content	7 to 12%
Angle of Friction	45-47 deg (static), 60% (self-emptying)
Angle of Repose	45-60 deg
Heating Value	
Rice Husk	2800 to 3100 kcal/kg
Char	2183 to 2600 kcal/kg
Ash Softening Temperature	Starts at 800°C
Ash Melting Temperature	>1000°C
Water Holding Capacity	5 to 7 times the weight of Carbonized Rice Hull
Carbon Sequestration Potential	0.63 tons of CO_2 per ton of biochar

ANNEX C

Sample design computation for a moving-bed downdraft rice husk gasifier

Assumptions:

Reactor Design Parameters

Feedstock = Rice husks
Specific gasification rate = 70 to 210 kg/hr-m^2
Air/Fuel ratio = 0.94 to 1.88 kg of air per kg
Stoichiometric air = 4.7 kg air per kg
Equivalence ratio = 0.2 to 0.4
Superficial gas velocity = 1.5 to 5 cm/s
Static pressure requirement = 1.0 to 1.5 cm of water per m depth
Fire zone rate = 1 to 3 cm/min
Gas heating value = 500 to 1200 kcal/m^3
Gasifier efficiency = 50 to 60%
Overall thermal efficiency = 10 to 40%
Char yield = 28 to 36%
Rice husk density = 100 kg/m^3
Char density = 92 kg/m^3

Gas Conditioning Parameters

Overall heat transfer coefficient of 3-pass gas tube heat exchanger = 11.72 kcal/hr-m^2-°C
Heat exchanger efficiency = 70 to 90%
Specific heat of gas = 0.6 kcal/kg-°C
Density of gas = 1.3 kg/m^3
Specific heat of air = 0.13 kcal/kg-°C
Filtration velocity = 0.01 to 0.07 m/s
Static pressure of filter = 1 cm H_2O

Engine Drive Parameters

Brake Power for Rice Mill = 20 hp

1. Design Power Required for the Engine Drive

Considering 20 hp brake power for the rice mill plus 50% of it for the parasitic load (fan, blower, conveyor and elevator), the total power can be calculated:

$P_d = P_m + P_p$
$= 20\text{ hp} + (2\text{ hp} + 2\text{ hp} + 1.5\text{ hp} + 3\text{ hp})$
$= 28.5\text{ hp}$

With the computed value for the designed power for the engine, the designer may choose the higher rated power for the engine. Thus, the designer can use 30 hp of engine drive.

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Furthermore, 30% brake thermal efficiency and 80% transmission efficiency will also be considered in calculating the engine power:

$P_e = P_d/(\xi bt \times \xi t)$
$= 30 \text{ hp} / (0.30 \times 0.80)$
$= 125 \text{ hp}$

2. Required Piston Displacement Rate for the Engine

The piston displacement rate of the engine can be calculated using the calculate engine power in KW and heating value of gas which is 1000 kcal/m³.

$PDR = P_e/(HVG)$
$= (125 \text{ hp} \times 0.746 \text{ kW/hp}) / (0.0012 \text{ kW/kcal/hr} \times 1000 \text{ kcal/m}^3)$
$= 77.7 \text{ m}^3/\text{hr}$

3. Required Piston Displacement Rate for the Engine

The gasifier when used for the engine can only provide an average speed of 1500 rpm, the engine piston displacement can be calculated by the engine displacement rate by the engine speed. Since the engine will be a 4 stroke engine, 2 will be multiplied and 1000 to convert m^3 to liters. Hence,

$PD = (2 \times PDR)/(N \times \xi v)$
$= (77.7 \text{ m}^3/\text{hr} \times 1 \text{ hr}/60 \text{ min} \times 1000 \text{ li/m}^3 \times 2)/ (1500 \text{ rpm} \times 0.8)$
$= 2.15 \text{ li}$

This means that an engine with at least 2.15 li piston displacement is needed. The designer will select the higher size to have enough power to compensate the additional power.

4. Selection of Engine based on the Computed Piston Displacement

In order to select the appropriate engine, the designer can based the computed piston displacement for its minimum value. The designer may opt to choose larger engine displacement to provide additional power.

5. Amount of Rice Husks Fuel Needed to Gasified

The airflow rate will be calculated with the gas-to-air ratio of 1.5 and the gas flow rate that is obtained from the computation of piston displacement rate. Thus, this can be computed by

$AFR = (PDR / GAR) \times \delta a$
$= (77.7 \text{ m}^3/\text{hr} / 1.5) \times 1.2 \text{ kg air/m}^3$
$= 62.16 \text{ kg of air/hr}$

Therefore, the blower needed to suck the air from the reactor and convert it into gas must have a rating that could meet 62.16 kg air/hr in terms of volumetric flow;

BFR = (AFR / AD)
= (62.16 kg air/hr)/ (1.2 kg air/m^3)
= (51.8 m^3/hr)

Therefore, amount of rice husk fuel needed with the stoichiometric air of rice husk of 4.7 kg air/kg of fuel and the stoichiometric air of 0.32:

FCR = AFR /(SA x ϵ)
= (62.16 kg air/hr)/ (4.7 kg air/kg fuel x 0.32)
= 41.33 kg fuel/hr

Thus, about 41.33 kg per hour of rice husk will need in powering the biomass gasifier.

6. Diameter of the Gasifier Reactor Inner Cylinder

The diameter of the gasifier reactor can be determined based on the design specific gasification rate. Using a pocket-type grate for the reactor, the specific gasification rate of 100 kg/hr-m^2 will be used. Calculating the reactor cross-sectional area for pocket-type grate will be considered to determine the diameter

A_r = FCR/SGR
= 41.38 kg/hr / 100 kg/hr-m^2
= 0.41 m^2

Hence, the diameter will be computed

$D_r = (1.27\ A_r)^{0.5}$
$= (1.27 \times 0.41\ m^2)^{0.5}$
= 0.72 m

The diameter to be used for the inner cylinder of the reactor is 0.7 m.

7. Diameter of the Gasifier Reactor Outer Cylinder

In order to calculate for the diameter of the gasifier reactor outer cylinder, the cross-sectional area of the inner cylinder must be equal to the cross-sectional are of the annular space between the inner and outer cylinders.

$D_o = 1.414 D_i$
= 1.414 x 0.7 m
= 0.99 m

The diameter to be used for the outer diameter is 1.0 m.

8. Diameter of the Gasifier Reactor Outer Cylinder

The height-to-diameter ratio used is H = 2D, the calculated height of inner cylinder will be

$H_r = 2 \times 0.7$ m
$= 1.4$ m

Additional 0.2 m will include in the height to provide allowance for the feeding of bucket elevator, the height of the inner cylinder will be 1.6 m. In addition, this means that a 1.2 m-wide metal plate rolled to form a cylinder with additional sliced of 0.4 m wide rolled along the length will give a total of 1.6 m-high inner cylinder.

9. Weight of Fuel Inside the Cylinder

For the computed reactor and designed height, the weight of rice husk fuel that can be placed inside the cylinder at full load and considering a rice husk density of 100 kg/m^3

$W_f = A_r \times H_r$
$= 0.41\ m^2 \times 1.6\ m \times 100\ kg/m^3$
$= 65.6$ kg

The weight of the rice husk inside the cylinder at full load is 65.6 kg.

10. Fire Zone Rate

The rate of fire zone movement to determine the location during the operation of gasifier can be computed by the fuel consumption rate, density of fuel and the area of the reactor

$FZR = FCR / (60 \times \delta f \times Ar)$
$= ((41.33\ kg\ fuel/hr \times 1\ hr/60\ min) / (100\ kg/m^3 \times 0.41\ m^2)) \times 100\ cm/m$
$= 1.7$ cm/min

Thus, the fire zone will reach the middle of the reactor (0.8 m) approximately 47 minutes while the top of the reactor (1.6 m) within 94 minutes.

11. Superficial Velocity of Gas at the Reactor

This can be calculated based on the airflow rate and area of the reactor

$SGV = AFR / (3600 \times \delta a \times Ar)$
$= (62.16\ kg/hr \times 1\ hr/3600\ s) / (1.2\ kg/m^3 \times 0.41\ m^2)$
$= 3.5$ cm/s

Since the channel formation will occur at 15 cm/s and above, there will be no channel formation expected at the bed of burning char during operation.

12. Required Static Pressure at the Reactor

The static pressure at the bed of rice husk is generally 1 cm of water per m depth. At the height of the reactor of 1.6 m, the static pressure required will be

SPr = SSP x Hr
= (1.6 m x 1.0 cm of water per m depth)
= 1.6 cm of water

Adding 0.3 cm of water for the pressure draft exerted at the annular space between the inner and the outer cylinders will give a maximum pressure draft for the gasifier reactor of

= 1.6 cm of water + 0.3 cm of water
= 1.9 cm of water

13. Amount of Char Produced During Operation

The amount of char produced is computed from the fuel consumption rate and the percent char yield.

CDR = FCR x CY
= 41.33 kg/hr x 0.3
= 12.4 kg/hr

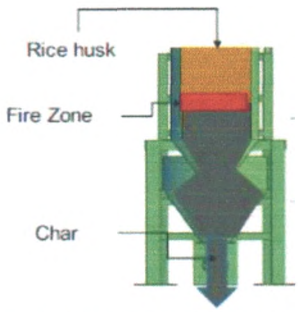

Figure 16. Diagram of Char Discharging

14. Char Discharging Capacity of the Grate

For pocket-type char grate, 8-pocket grate with capacity to load half at a time 7.5 cm thick char per sway will be used. The distance of the grate from the inner cylinder bottom will be at 15 cm in order to minimize the heating of the grate. In order to calculate the discharged per complete sway of the lever, area of the reactor, depth, volumetric efficiency, and density of char will be considered. The schematic diagram is shown below.

Cg = Ar x Dg x δc x ξv
= 0.41 m^2 x 0.075 m x 0.80 x 92 kg/m^3
= 2.3 kg/sway

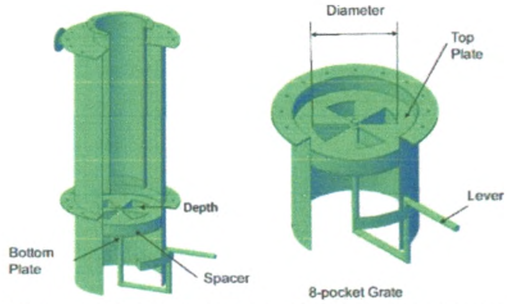

Figure 17. Diagram of a Pocket-type Grate

Hence, the number of sways required per hour will be

Number of sways per hour = CDR/Cg
= 12.4 kg/hr / 2.3 kg/sway
= 5.4 sways per hour

Therefore, every 11 or 12 minutes, the lever must be swayed to discharge the char.

15. Diameter of Gas Pipe

In case of gas pipe, the velocity of the gas to be considered in the design must be more than 20 cm/s in order to prevent the char from getting stacked up in the pipe which may cause clogging and subsequently increase the pressure draft requirement of the suction blower. Using 1.5 m/s gas velocity, the area of the gas pipe should be

Ap = GFR/Vg
= 77.7 m^3/hr / (1.5 m/s x 3600 s/1 hr)
= 0.014 m^2

The pipe diameter would be

Dp = $[4 \times Ap / \pi]^{0.5}$
= $[4 \times 0.014\ m^2 / \pi]^{0.5}$
= 0.13 m

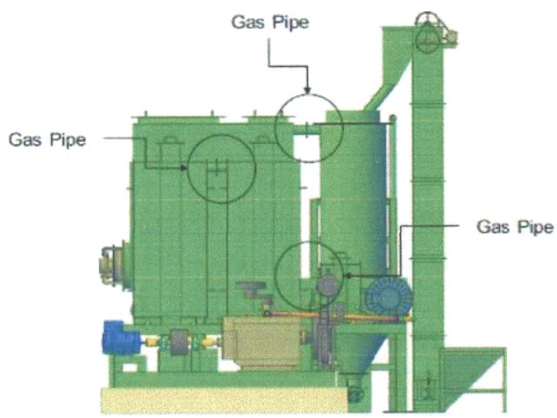

Figure 18. Diagram of Gas Pipe

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Therefore, it is recommended to use 5 in. gas pipe. The design for the length of gas pipe should be short enough so that tar will not heavily accumulate at the inner surface of pipe when the char particles go with the gas.

16. Heat Input to the Heat Exchanger

To calculate the heat input to the pipe by the gas that enters the heat exchanger pipes, considering a 0.6 kcal/kg-°C specific heat of gas entering at 250°C and leaving at 80°C, and at 1.3 kg/m³ density, will give a heat load of

$$Qh = mg \times cp \times (Ti - To)$$
$$= 77.7\ m^3/hr \times 1.3\ kg/m^3 \times 0.60\ kcal/kg\text{-}^\circ C \times (250\ ^\circ C - 80\ ^\circ C)$$
$$= 10{,}303.02\ kcal/hr$$

17. Area of Heat Exchanger Pipe

The total surface area of the heat exchanger pipe in order to drop the temperature of the gas from 250°C down to 80°C at 30°C ambient air temperature using an overall heat transfer coefficient of 11.72 kcal/hr-m² °C will be

$$Ahe = Qh / U \times (((T_2 - Ta) - (T_1 - T_a)) / 2)$$
$$= 10{,}303.02\ kcal/hr / [11.72\ kcal/m^2\text{-}hr\text{-}^\circ C \times 85\ ^\circ C]$$
$$= 10.34\ m^2$$

18. Number of Heat Exchanger Pipe

Using a 2 in.-diameter boiler pipe schedule 40 with g=height of 2 meters, the surface area of each pipe with the given dimension is

$$Ap = \pi \times Dp \times Lp$$
$$= \pi \times 0.05\ m \times 2\ m$$
$$= 0.32\ m^2$$

Therefore, the number of pipes needed for the heat exchanger will be

$$Np = Ahe / Ap$$
$$= 10.34\ m^2 / 0.32\ m^2$$
$$= 32.32$$

Hence, 34 pcs of 2 in. diameter by 2m long pipe schedule 40 or 6 m 12 lenghths of pipes will be used.

19. Pressure Draft Required for Heat Exchanger

Specific draft ranges from 0.2 to 1.9 mm H_2O per m length of the pipe. Therefore, at 2 m high on 3 –pass design, the draft needed is

SPh = SSPp x Lp
= 1.9 mm H_2O x 2 m/pass x 3 pass
= 11.4 mm H_2O x 1 cm/ 10 mm
= 1.14 cm of H_2O

20. Amount of Air needed for Cooling the Heat Exchanger Pipes

This can be computed using heat and mass balance formula between the gas and the air in cooling the pipes. Considering a 70% heat exchanger efficiency, the mass of air need is

Ma = Mg x Cpg x (Tg1 – Tg2) / (Cpa (Ta1 – Ta2) x ξhe)
= 10, 303.02 kcla/hr / [0.13 kcal/kg-°C x (250 °C - 30 °C) x 0.70)
= 514.63 kg/hr

Dividing by the density of air of 1.2 kg/m^3 will give

= 428.86 m^3/hr or 7.15 m^3/min

21. Cross-sectional Area of Vertical Packed-Bed Filter

Two packed bed identical filters in series will be utilized for the gasifier to ensure that gas will be fully cleaned before it will be injected into the intake manifold of the engine. The designer can use their preferred filter material. In this case, rice husk will be used as filter material for it can be easily replaced from time to time and once discharged and dried can still be used to fuel in the gasifier.

Considering a 0.03 m/s filtration velocity and a gas flow rate of 77.7 m^3/hr, the cross-sectional area required for the filter will be

$Af_{1\&2}$ = GFR/ V_f
= (77.7 m^3/hr x 1 hr/3600 s) / 0.03 m/s
= 0.71 m^2

The filter width considered is 0.4 m, the height will be

Hf = 0.71 m^2/ 0.4 m
= 1.79 m

Therefore, the height of the filter will be 1.8 m.

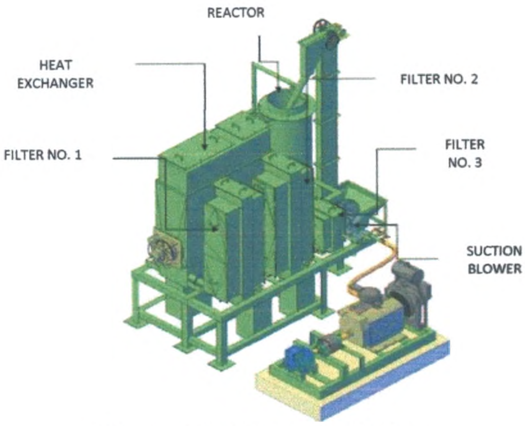

Figure 19. Diagram of Filter

22. Cross-sectional Area of Vertical Packed-Bed Filter

The first filter, 0.4 m-thick column will be designed to facilitate replacement of filter material once tar had accumulated enough amount in the filter. For the 2nd filter, the design will be 0.3 m-thick column. The pressure draft for the two filters will be as follows

$SPf_1 = SSPf / t_f$
$= 1$ cm of H_2O/m depth x 0.4 m
$= 0.4$ cm of H_2O

$SPf_2 = SSPf / t_f$
$= 1$ cm of H_2O/m depth x 0.3 m
$= 0.3$ cm of H_2O

Total pressure draft for two filters will be

$SPf_t = SPf_1 + SPf_2$
$= 0.4$ cm of H_2O + 0.3 cm of H_2O
$= 0.7$ cm of H_2O

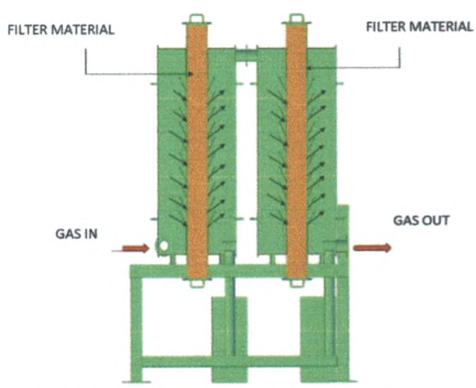

Figure 20. Vertical Packed-Filter

23. Cross-sectional Area of Vertical Packed-Bed Filter

The final filter with higher filtration velocity of 4 ties than the two filters will be provided to further ensure cleaner and cooler gas is obtained. Considering a 0.12 m/s filtration velocity, the cross-sectional area for filter will be

$Af_3 = (77.7\ m^3/hr \times 1\ hr/3600s)/0.12\ m/s$
$= 0.18\ m^2$

Using the width of the filter of 0.4 m, the filter height,

$Hf_3 = 0.18\ m^2 / 0.4\ m$
$= 0.45$ m or use 0.5 m high

If 0.3 m-thick column will be adopted, the pressure draft will be similar to that of filter no.2 which is 0.3 of H_2O.

24. Expected Volume of Tar Collected

At 77.7 m^3/hr gas flow rate, the amount of tar that can be collected is

VFRt = GFR x STP
$= 77.7\ m^3/hr \times 0.004\ li/m^3$
$= 0.3108$ li/hr

On the other hand, the amount of water that can be collected is computed based on the initial and final weight and moisture of rice husk.

Therefore, a ball valve needs to be provided for the footer of heat exchanger as well as at the entrance of filter no. 1 for easy discharge of the tar and water during continuous operation.

25. Gas Flow Rate and Total Pressure at Gasifier

With the computed engine displacement rate, gas flow rate can be calculated. The volumetric flow is the amount of gas that the engine can receive during the operation of the gasifier. In the case of the pressure draft, the computed pressure draft for each component of the gasifier can be added to get the total pressure needed when specifying the suction blower. Hence,

$TSP = SPr + SPhe + SPf_1 + SPf_2 + SPf_3$
$= (1.9 + 1.14 + 0.4 + 0.3 + 0.3)$ cm of H_2O
$= 4.04$ cm of H_2O

Therefore, the suction blower to be selected must be able to pull the gas at a rate of 77.7 m^3/hr and at a pressure head of 4.04 or at 5.0 cm of water.

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