Skill Enhancement and Laboratory Exposure Training Manual on Sub-Megawatt Scale Biomass Power Generation

Under the project

"Removal of Barriers to Biomass Power Generation in India"

Supported by

United Nations Development Programme
New Delhi

Prepared by

The Energy and Resources Institute
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Preface

The power sector in India has an installed capacity of 236.38 Gigawatt (GW) as on March 2012, which is an increase of 14 percent from 2011. An additional 36.5 GW is generated through captive power plants. Out of the installed capacity, thermal power plants constitute 66 percent of the capacity, hydroelectric about 19 percent, and the rest being a combination of wind, small hydro-plants, biomass, waste-to-electricity plants, and nuclear energy.

The installed capacity in India of biomass-based power generation is around 3,600 MW as on June 2013 (as per MNRE). There is potential of generating 17,000 MW power from biomass residues and an additional 5,000 MW through biomass cogeneration. According to Energy Alternatives India, the total installed capacity of biomass gasification based power is only about 140 MW out of 2,600 MW. The rest is constituted by bagasse-based power generation (about 1,400 MW) followed by combustion-based biomass power production (about 875 MW). Therefore, there are lots of opportunities in terms of biomass gasifier based power generation in India.

In recent years, many companies have implemented biomass gasification plants in different parts of the country but large-scale dissemination of the technology still faces many barriers. One of the key barriers for the development of biomass based power systems is non-availability of skilled manpower. There are several biomass based technologies but only a few are successfully demonstrated. For proper operation and maintenance of the implemented systems, the operators need to be trained. Presently, most of the system operators are not well trained and is thus affecting the performance of the gasification system.

With a view to provide training on biomass gasifier systems to operators and technicians, UNDP-GEF-MNRE has awarded a joint project to TERI and UPES for conducting a skill enhancement training for technicians under the project "Removal of Barriers to Biomass Power Generation in India." The training is a step towards removing the technical barrier for promotion of biomass based systems. The technicians chosen for this training were from technical institutes, operators of existing biomass gasifier plants, and local service providers. They were provided with the working knowledge and hands on experience on biomass based power systems under the training programme.

It is believed that the manual will serve as a reference guide for technicians and operators who are working in the field of gasifiers and will provide descriptive knowledge of existing technologies, operation and maintenance, and performance evaluation of the biomass gasifier system.

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Executive Summary

India's installed electricity capacity has increased rapidly in recent years, from 120 GW in 2005 to 210 GW in 2012. Despite this, 56 per cent of rural households don't have access to electricity. Extending the grid to every village and providing these villages with reliable power supply is a challenge. Further, there is a shortage of 10.6 per cent of the total electricity demand in the country, which is hindering the productivity of small scale industries, with even grid-connected industries often experiencing long power cuts.

Therefore, there is a need for decentralized electricity generation, which can provide reliable power supply to grid-unconnected rural households, as well as to small scale industries experiencing power shortages. Biomass is an important energy source, contributing almost 40 per cent of primary energy requirement of India. An improvement in the biomass energy production and conversion technologies is considered one of the important potential strategies to meet the growing challenge of energy security in the country. Estimates suggest that while, at present, as much as 19,500 MW of electricity can be generated through biomass, only around 1000 MW is being generated. Also, the conversion efficiency with biomass is still quite low. Most of the biomass power plants that do exist are of 5 MW and higher in capacity, but there is a requirement for small scale plants in the capacity range of 100 kW to 2 MW, which presently is largely unmet. There are several reasons for this shortfall but the prime reasons include weak institutional and financing mechanisms, policy framework, and technical capacities.

With an aim of promoting the large scale dissemination of biomass gasifier-based power generation, UNDP has focused on the removal of technical, regulatory, and institutional barriers related to this area. In this regard, UNDP has awarded a project titled "Sensitization Workshop and Skill Development Training on Sub megawatt Scale Biomass Power Generation under the programme: Removal of Barriers to Biomass Based Power Generation" to The Energy and Resources Institute (TERI) and University of Petroleum and Energy Studies (UPES). The objectives of the project include sensitization to the potential investors about the sub-megawatt scale biomass power systems, and enhancing technical skills of manufacturers, operators, and technicians in carrying out O&M of the biomass gasifier systems.

Unskilled manpower is one of the key issues related to biomass-based power generation in the country. Therefore, under the project, training programme on Skill Enhancement and Laboratory Exposure for LSPs, Industrial Training Institute (ITIs), gasifier manufacturers and suppliers, micro-enterprises, implementing agencies etc. was done. In all 22 participants representing ITIs, operators and manufacturers already working in the biomass sector were trained. The students were provided 10 days hands on training on biomass gasifier system that included work related to assemble, operation, and maintenance of the biomass gasifier system. They were also provided training in laboratory on quality of producer gas produced, and efficiency of biomass system etc. A field visit was also conducted to showcase the on-ground application of the biomass gasifier technology. All the candidates were examined at the end of the training programme and later certificates were provided.

Definitions

Term	Definition
Air-Fuel ratio	The quantity of air added to the gasifier or engine per unit of quantity of fuel.
Ash	The solid residue left after complete combustion of the biomass in air, consisting primarily of metal oxides.
Auxiliary Power Consumption	Power consumed by system accessories such as blower, pump, automated feeding systems, etc.
Biomass	Biomass is a term for all organic material that stems from plants (including algae, trees, and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis, and includes all land and water-based vegetation, as well as all organic wastes.
Consumption Rate	The rate at which the feedstock is consumed in a biomass gasifier, as measured in Kg/hr. It is calculated as the total wood consumed in kilograms divided by total number of hours of operation for a gasifier system.
Biomass Gasification	Biomass gasification is the process of partial combustion of biomass under controlled air supply producing mixture of gases called producer gas.
Bridging	This is a problem that occurs in gasifiers when the fuel does not burn properly, leading to the formation of bridges inside the gasifier resulting in blockage of gas flow. Bridges are the constricted passage formed due to accumulation of tar compounds with the solid biomass, leading to a very tight clinker-like formation, which inhibits burning inside the reactor.
Cold Gas Efficiency of Gasifier	The cold gas efficiency is calculated only on the basis of calorific value of the purified and cooled gas, and hence is lower than the hot gas efficiency.
Combustion	Combustion process involves the direct burning of the biomass material in air; the carbon and hydrogen in the fuel react with oxygen ultimately to form carbon dioxide and water.
Cross-draft Gasifier	A gasifier where the biomass enters from the top and leaves from the bottom, while the air enters from one side of the gasifier, towards the lower portion, and flows across the bed. The producer gas is extracted opposite the air nozzle on one side of the gasifier.
Density	The density of a material is its mass per unit volume. It is measured in terms of kg/m^3.
Down-draft Gasifier	Also called a co-current gasifier, it is one where the pyrolysis zone is above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top, air in the middle section, and gas is extracted from the bottom of the gasifier.
Down-time	It is the time during which the gasification system is not in-operation due to maintenance.
Electricity	The flow of electric charge from higher potential to lower potential. This can be used to run appliances, in lighting, etc.

Engine Exhaust Emissions Fixed Carbon (FC)	The gases emitted by the engine after burning the fuel to generate power mainly comprised of CO_2 with small amount of NOx and CO. The mass remaining after the release of volatiles, excluding the ash, and moisture content.
Gross Calorific Value (GCV)	The GCV is the total energy content released when the fuel is burnt in air, including the latent heat contained in the water vapour and therefore, represents the maximum amount of energy potentially recoverable from a given biomass.
Hot Gas Efficiency of Gasifier	The hot gas efficiency is calculated in terms of the gas as it leaves the gasifier, before entering the cleaning-cooling system. In addition to the calorific value of the producer gas, the calculation includes the calorific value of the tar and soot contained in the raw gas, and the sensible energy of all the constituents of the hot raw gas.
Moisture Content (MC)	The quantity of water present in the biomass, measured as kilogram of water per kilogram of biomass.
Naturally Aspirated Engine	An engine where the air-fuel mixture is drawn into the cylinders using atmospheric pressure alone.
Net Calorific Value (NCV)	NCV can be calculated as GCV- latent heat of water vapour.
Photosynthesis	Photosynthesis is a complex set of reactions in which carbon dioxide is reduced to carbohydrates using light and water.
Plant Load Factor (PLF)	A measure of average capacity utilization, calculated by dividing the actual electricity generated by a plant by the electricity that would have been generated when the plant has run continuously over time period in question.
Pressure	Pressure is the ratio of force to the area over which that force is distributed. It is measured in Pascal or mm of mercury or water column.
Producer gas	Producer gas is a mixture of hydrogen, carbon monoxide, carbon dioxide, nitrogen, and methane produced by biomass gasification. The typical composition is $H_2 = 18 \pm 2$, $CO_2 = 8 \pm 3$, $CO = 19 \pm 3$, CH_4 = 1-3, $N_2 = 45 \pm 50$.
Proximate Analysis	An analysis to determine the moisture content, volatile matter, ash content, and fixed carbon in a fuel sample.
Pyrolysis	The thermal treatment of biomass in the near absence of oxygen at a temperature of around 500°C is called pyrolysis.
Specific Biomass Consumption	The amount of biomass consumed per unit of electricity generated, as measured in kg/kWh.
Tar compounds	The black sticky substances, which are liquids at room temperature, produced during biomass gasification. A mixture of hydrocarbons and free carbon, their formation during gasification should be minimized and an effective cleaning system should be used for their removal to prevent deterioration of engine life.
Temperature	Temperature is a physical quantity that is a measure of hotness and coldness on a numerical scale. It is measured in degree Celsius or Kelvin.

Turn-down ratio	The ratio of minimum to the maximum gas output of a gasifier or power output of an engine.
Updraft Gasifier	A gasifier where the fuel is fed from the top and the air from the bottom, with the producer gas being removed at the top.
Ultimate Analysis	An analysis to determine the elemental composition of a fuel sample.
Volatile Matter (VM)	The portion of biomass driven-off as a gas by heating.

1. Biomass Gasification

1.1 Biomass types and properties

Biomass is a term for all organic material that comes from plants (including algae, trees, and crops). Biomass is produced by green plants that convert sunlight into plant material through photosynthesis, and includes all land, and water-based vegetation, as well as all organic wastes. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. Biomass has always been a major source of energy.

Biomass types can be defined in different ways, but one simple method is to define as:

- Plant derived
- Animal derived

The plant derived biomass resources can be further divided into woody and non-woody biomass. Woody biomass includes trees and tree residues, and energy plantation, etc., while non-woody biomass includes agricultural residues, aquatic, and marine plants, etc. On the other hand, animal-derived biomass can be considered as municipal solid waste, sludge, etc. (Kishore 2008). The animal-derived biomass, in general, is not used for gasification purpose and, therefore, their characteristic properties have not been discussed in this manual.

Each type of biomass has specific properties that determine its performance as a fuel in combustion, or gasification devices, or both. The most important properties relating to the thermal conversion are:

a. ***Moisture Content:*** The moisture content of biomass is the quantity of water present in the biomass. The moisture content affects the value of biomass as a fuel. This is particularly important because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from less than 10 per cent for cereal grain straw up to 50 to 70 per cent for forest residues.
b. ***Ash Content:*** The chemical breakdown of a biomass fuel, by either thermo-chemical or bio-chemical processes, produces a solid residue. When produced by combustion in air, this solid residue is called ‘ash’. The ash content of biomass affects both the handling and processing costs of the overall biomass energy conversion cost. Dependent on the magnitude of the ash content, the available energy of the fuel is reduced proportionately. In a thermo-chemical conversion process, the chemical composition of the ash can present significant operational problems. This is especially true for combustion processes, where the ash can react to form a ‘slag’, a liquid phase formed at elevated temperatures, which can reduce plant throughput, and result in increased operating costs.
c. ***Volatile Matter, and Fixed Carbon content:*** The Volatile Content, or Volatile Matter (VM) of a solid fuel is that portion which is driven-off as a gas (including moisture) by heating, and the Fixed Carbon content (FC), is the mass remaining after the releases of volatiles, excluding ash, and moisture contents. These two parameters are important to analyse as in solid fuels chemical energy is stored in two forms, fixed carbon and volatiles. Fuel analysis based upon the VM content, ash, and moisture, with the FC determined by difference, is termed as the proximate analysis of a fuel.

d. Calorific Value: The Calorific Value (CV) of a material is an expression of the energy content, or heat value released when burnt in air. The CV is usually measured in terms of the energy content per unit mass, or volume; hence MJ/kg for biomass. The CV of a fuel can be expressed in two forms, the Gross Caloric Value (GCV) or Higher Heating Value (HHV), and the Net Caloric Value (NCV) or Lower Heating Value (LHV). The HHV is the total energy content released when the fuel is burnt in air including the latent heat contained in the water vapour, and therefore, represents the maximum amount of energy potentially recoverable from a given biomass source. In practical terms, the latent heat contained in the water vapour cannot be used effectively and, therefore, the LHV is the appropriate value to use for the energy available for subsequent use.

e. Bulk Density: An important characteristic of biomass materials is their bulk density, or volume, both as-produced, and as-subsequently processed. The importance of the as-produced bulk density is in relation to transport, and storage costs. The density of the processed product impacts fuel storage requirements, the sizing of the materials handling system, and how the material is likely to be have during subsequent thermo-chemical/biological processing as a fuel/feedstock.

1.2 Biomass based conversion technologies

Biomass can be used for heating, electricity generation, steam generation, and mechanical or shaft power applications. It also produces a variety of chemicals as by-products. There are different conversion processes for obtaining different products, which can be broadly classified as thermo- chemical, and bio-chemical conversion technologies.

Thermo-chemical

Thermochemical conversions are based on thermal treatment of biomass. The various thermal treatments can be broadly classified into combustion, gasification, and pyrolysis.

a. Combustion: Combustion process involves direct burning of the biomass material in air; the carbon, and hydrogen in the fuel react with oxygen to form carbon dioxide, and water through a series of free radical reactions liberating heat. Combustion is the most direct process of biomass conversion into energy that can be used for a variety of applications.

b. Pyrolysis: The thermal destructive distillation of biomass in the absence of oxygen at a temperature of around 500°C is called pyrolysis. The products obtained from biomass pyrolysis primarily consist of non-condensable gasses, liquid bio oil (bio-crude), and residue bio-char. The bio crude (bio oil) obtained via fast pyrolysis of biomass has potential to be used as heavy fuel oil for heat, and power applications, or be upgraded for conventional refinery operations similar to petroleum crude.

c. Gasification: Gasification is based on the partial oxidation of the biomass in order to convert it into a mixture of gasses predominantly containing carbon monoxide, and hydrogen known as syngas. Syngas can be further processed downstream to be used in other applications.

Biochemical

Biochemical conversion makes use of the enzymes of bacteria, and other micro-organisms to break down biomass. In most cases micro-organisms are used to perform the conversion process:

a. Anaerobic digestion: It is a series of bio-chemical processes in which microorganisms break down bio-degradable materials in the absence of oxygen and generate methane.

b. Ethanol fermentation: It is a bio-chemical process in which sugars are converted into energy, and thereby produce ethanol, and carbon dioxide as metabolic waste products.

1.3 Biomass gasification

Biomass gasification is the process of partial combustion of biomass under controlled air supply, thus producing a mixture of gases called "Producer gas". It is a thermo-chemical (chemical, and heat) process in which solid biomass is converted into a gaseous fuel by a series of chemical reactions. Producer gas consists of a mixture of combustible gases such as hydrogen (H_2), carbon monoxide (CO), and methane (CH_4), and incombustible gases such as carbon dioxide (CO_2), and nitrogen (N_2). In a gasifier, biomass is heated from the ambient temperature to a temperature of around 1100°C. The main reactions which take place in a gasifier are shown in figure 1.1.

a. *Drying:* Biomass fuels usually contain moisture in range of 10 and 35 per cent. When the biomass is heated to around 100°C, the moisture gets converted into steam.

b. *Pyrolysis:* After drying after biomass is heated, it undergoes pyrolysis. Pyrolysis is the thermal decomposition of biomass fuels in the absence of oxygen. Biomass decomposes into solid charcoal, liquid tars, and gases.

c. *Oxidation*: Air is introduced in a gasifier in the oxidation zone. In oxidation, taking place at about 700-1400°C, the solid carbonized fuel reacts with oxygen in the air producing carbon dioxide, and releasing heat.

d. $C+O_2 = CO_2 + 393800$ KJ/Kg

e. *Reduction*: At higher temperatures, and under reducing conditions, the following reactions take place resulting in formation of CO, H_2, and CH_4.

$CO_2 + C = 2CO - 172600$ KJ/Kg mole

$C + H_2O = CO_2 + H_2 - 131400$ KJ/Kg

$CO_2 + H_2O = CO_2 + H_2 + 41200$ KJ/Kg mole

$C + 2H_2 = CH_4 + 7500$ KJ/Kg mole

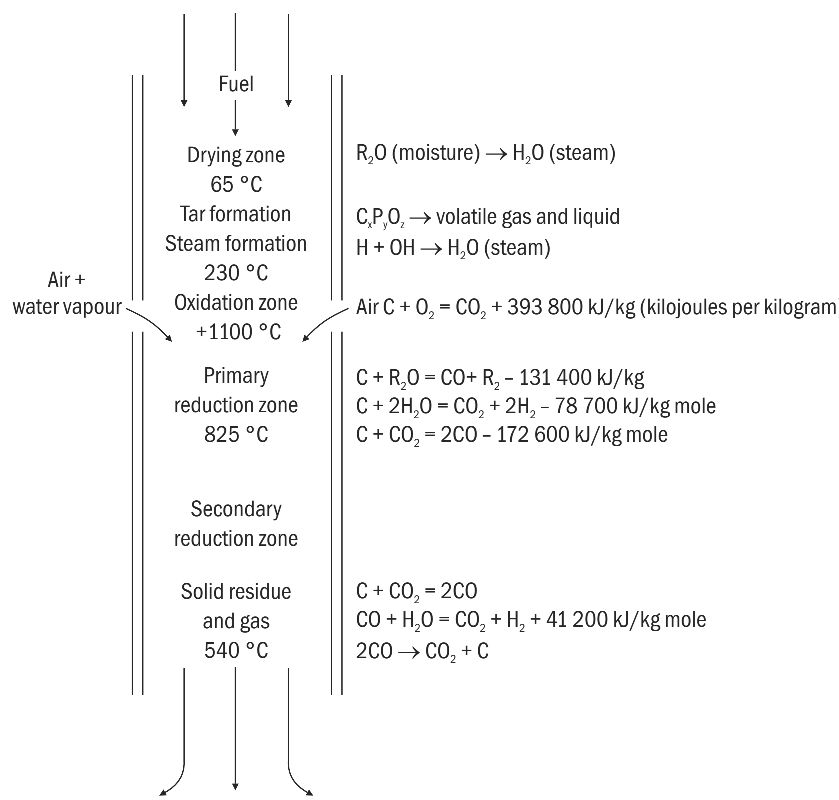

Figure 1.1: Sequence of reactions in a downdraft gasifier

The calorific value (energy per unit mass) of the producer gas is about 1000 – 1200 kilocalories/m^3 or 4.0 and 6.0 MJ/Nm^3. Approximately 2.5 Nm^3 [1] of producer gas is obtained from the gasification of 1kg of woody biomass using atmospheric air as gasifying agent.

Producer gas can be used for the generation of motive power either in dual fuel engines (where gas, and diesel are mixed, and combusted together in the engine), or in diesel engines that have undergone some modification. Engines operating on a spark-ignition system (e.g. petrol engines) can be made to run entirely on producer gas, whereas those using compression ignition systems (e.g. diesel engines) can be made to operate with about 60 to 80 per cent diesel replacement by the gas. A rough performance ratio for electricity produced from gasifier-based systems is:

a. 0.9 - 1.1 kg of biomass/kWh in the dual fuel-mode of operation.

b. 1.5 - 1.8 kg of biomass/kWh in 100 per cent producer gas engine operation.

Producer gas can also be burnt directly in air much like LPG gas, and therefore finds useful applications in cooking, water boiling, steam production, and food and materials drying. In general, the fuel-to-electricity efficiencies of thermo-chemical processes such as gasification are much higher than those of direct combustion, since gasification converts approximately 35 to 45 per cent of embodied energy, whereas combustion converts only 10 to 20 per cent.

1.4 Types of biomass gasifiers

Gasifiers are of various types scaled from small to large system. The small scale biomass gasifier systems are mostly fixed bed reactors. In all gasifiers, the gasification of solid fuels containing carbon, such as wood, takes place in an air-sealed chamber under a slight vacuum, or pressure. The fuel column is ignited at one point, and exposed to a continuous air blast during operation with the producer gas being drawn off at another location. Depending upon the positions of the air inlet, and gas withdrawal, the types of gasifiers generally used are:

a. **Downdraft or Co-current gasifier**: In the downdraft gasifier, or co-current type, the pyrolysis zone is above the combustion zone, and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow

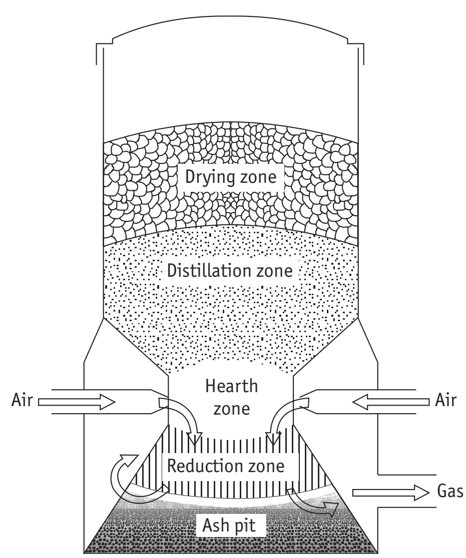

Figure 1.2: Downdraft Gasifier

1 The calorific value (energy per unit mass) of the producer gas is about 1000-12000 kilocalories/m^3 or 4.0 and 6.0 MJ/Nm^3. Approximately (2.5 Nm^3)[1] of producer gas is obtained from the gasification of 1kg of woody biomass using atmospheric air as gasifying agent.

of air is downward through the combustion, and reduction zones as shown in figure 1.2. The term co-current refers to the fact that the movement of air is in the same direction as that of the fuel. The essential characteristic of the downdraft gasifier is that it is designed in such a way that the tars given off in the pyrolysis zone travels through the combustion zone where they will be broken down or burned. As a result, energy is released, and the mixture of gases in the exit stream is relatively clean. The arrangement of combustion zone is thus a critical element in the downdraft gasifier. Downdraft gasifiers are used mostly in power applications.

b. **Updraft or counter-current gasifier**: In the counter-current or updraft gasifier, the air flows counter to the downward fuel flow, and enters into the gasifier from below the grate, and flows in the upward direction within the gasifier (see fig. 1.3). An updraft gasifier has distinctly defined zones for partial combustion, reduction, and devolatilization. The gas produced in the reduction zone leaves the gasifier reactor together with the pyrolysis products, and the steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons, and therefore has a relatively higher calorific value. The gas produced in updraft gasifier has high tar content and impurities and is mostly used in thermal applications.

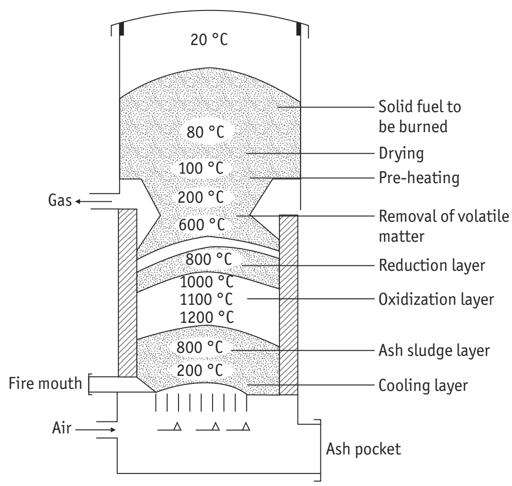

Figure 1.3: Updraft gasifier

c. **Cross-draft gasifier**: In a cross-draft gasifier, air enters from one side of the gasifier reactor, and leaves from the other side as indicated in figure 1.4. Cross draft gasifiers are slightly better than the updraft gasifiers but not useful as the downdraft gasifiers. Therefore their use for thermal and power

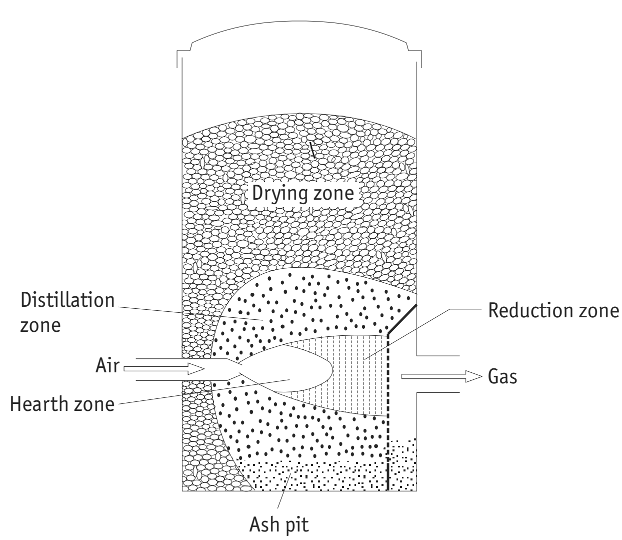

Figure 1.4: Cross-draft gasifier

1.5 Application of biomass gasifiers

The producer gas obtained by the process of gasification can have end-use for thermal application, or for mechanical/electrical power generation. Producer gas can be used for decentralized power generation, water pumping, and for a variety of thermal applications. In locations, where biomass is already available at reasonably low prices (e.g., rice mills, corn processing units, sugar mills, etc.), or in applications utilizing fuel wood (e.g., institutional cooking, silk reeling units, etc.), biomass gasifier based systems offer definite economic advantages. The producer gas can be conveniently used in number of applications as mentioned in subsequent paragraphs.

1.5.1 Industrial thermal applications

Thermal energy of the order of 4–6MJ is released on combustion of 1m^3 of producer gas in the burner. Flame temperatures up to 900-1100°C can be obtained by optimal pre-mixing of air with gas. For applications which require thermal energy, gasifier is a good option, and it is used in the following applications:

Dryers: Drying is the most essential process in beverage and spice industries like tea and cardamom. This calls for hot gases in the temperature range of 120–130°C in the existing designs. Typically, the heat energy required is equivalent to 1kg of wood for 1kg tea made. Gasifier is an ideal solution for the above situation where hot gas after combustion can be mixed with the right quantity of secondary air, so as to lower its temperature to the desired level for use in the existing dryers.

Kilns: Firing of tiles, potteries, limestone, and refractories require hot environment in the temperature range of 800–950^{0}C. Gasifiers are used for such applications as they provide a better option for regulating the thermal environment. There will also be an added advantage of smokeless and sootless operation, thereby enhancing the product value. This is presently being done by combusting large quantities of wood in an inefficient manner. Lime kilns in Paonta Saheb, Himachal Pradesh, are using charcoal-based producer gas for their heating requirements.

Furnaces: In steel re-rolling mills, non-ferrous metallurgical, and foundry industries high temperatures

Figure 1.5: Thermal applications in metal industry

Boilers: Process industries that require steam or hot water use either biomass, or coal as fuel in the boilers. Biomass is used inefficiently with high emissions of pollutants like particulate matter, NOx, and with little control with respect to power regulation. Therefore, these devices are appropriate to be retrofitted with gasifier for efficient energy usage.

Retort heating: Producer gas is used for heating retorts; retorts, in turn, carbonize non-caking coals. Dankuni Coal Complex (DCC), Dankuni, West Bengal, uses producer gas for heating continuous vertical retorts.

1.5.2 Power generation

Using producer gas, it is possible to operate a diesel engine either on 100 per cent gas, or on dual fuel mode. Diesel substitution of order of 80 to 85 per cent can be obtained at nominal loads. The mechanical energy, thus, derived can be used either for energizing a water pump set for irrigation purpose, or for coupling with an alternator for electrical power generation, either for local consumption, or for grid synchronization.

Chilling/cold storage applications: Wherein both thermal energy (for washing/absorption refrigeration) as well as power could be produced in requisite proportions.

Co-generation applications: Simultaneous production of charcoal and power, wherein energy inefficiency and air pollution problems of traditional charcoal making are converted to electricity as a by-product.

Agricultural/irrigational uses: The use of biomass gasifier in agricultural sector especially for smaller farmers has tremendous use, when they are linked to 5 hp to 10 hp pump sets. In majority of the developing countries, the regularity in grid supply at village level is very poor (rather less than 25 per cent); in these cases it becomes very useful. A localized gasifier-based power generation system can be an ideal choice for energizing a number of pump sets (5 to 20) through a local grid.

1.6 Types of cooling and cleaning system for power generation

A gasifier system consists of a biomass gasifier that converts solid fuel into combustible gas, a cleaning-cooling system that removes impurities like dust particles, and tar vapours present in the producer gas coming out of the reactor of the gasifier, and an internal combustion engine for power generation. The cooling cleaning system of gasifier can vary on the basis of design, and impurity levels with essential components of gasifier in the section. A schematic of biomass power generation system is provided in figure 1.6.

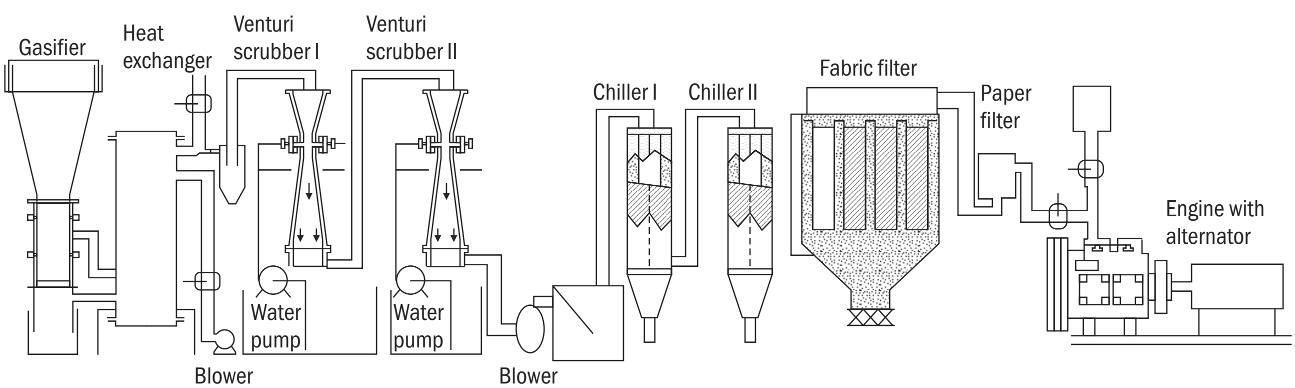

Figure 1.6: Schematic of a complete gasification-based power system

Heat Exchanger: The heat exchanger-cum-dust settling chamber has been introduced to exchange the heat with the air as well as to remove the heavier dust particles in the gas stream coming out from gasifier. The air takes the heat from the gas, and then this pre-heated air is again fed to the gasifier, thus, increasing its efficiency. A photograph of heat exchanger is given in figure 1.7.

Figure 1.7: Heat exchanger is used to preheat the air via heat exchange with the hot producer gas

Cyclone separator: The contaminated gas stream is passed into a cylindrical chamber called the Cyclone Separator (see fig. 1.8) where the tangential entry of the gas leads to the dust removal through centrifugal action. Here the finer particles of the dust are removed, due to which it needs regular maintenance (which depends on the pressure drop across the filter).

Figure 1.8: Cyclone Separators are used for dust removal from the raw producer gas

Venturi Scrubber: It consists of a converged neck (the narrowest part of the venturi tube), a diverging expansion chamber, and beyond that a drip precipitator (see fig. 1.9). The dust/gas mixture streams into the venturi tube, and reaches high speeds in the neck. Then, the mixture reaches the expansion chamber where the speed diminishes. The water is added to the gas just before or inside the neck. Due to the high speed attained by the gas and liquid, the water scatters into small drops resulting in an intense contact between the gas, and liquid phases. The venturi scrubber is made to cool the gas up to the ambient temperature by sprinkling water through nozzle in the main gas line. The water is sprinkled on the gas from the nozzle with the help of pump, and solves two purposes:

- It removes the tar through condensation that gets collected in the water pit itself.
- It cools the gas by exchanging its heat with the duct surface, and water.

Moisture separator/ Gravel bed: The gas stream, which is moisture laden following its passage through the venturi scrubbers, is next passed through moisture separator to condense the moisture, and bring down the gas temperature to a value suitable for passage into the subsequent filter assembly. One option can be the gravel bed that can be used immediately after the venturi scrubber, and is used mainly to remove the moisture carried away by the gas from the venturi scrubber. The principle used in the gravel bed filter is separation through impaction[2].

Fabric filter: The fabric filter made of synthetic filter material with nylon mesh roped over it is introduced to arrest even the finer dust particles present in the gas stream. The water present in the stream also gets drained off in the filter. A photograph of fabric filter is provided in figure.

Figure 1.9: Venturi Scrubber (used for cleaning the producer gas with water) and Fabric filter (used for separating minute impurities from the producer gas)

2 Impaction refers to the removal of particles from a gas stream by forcing the gases to make a sharp turn. The solid particles, being heavier than the gas molecules, possess higher momentum, and cannot follow the gas stream. These particles strike the wall of the vessel, and are, thus, removed from the stream.

Paper filter*:* Finally, a paper filter is used as a safety filter to ensure that clean gas with permissible levels of tar and particulates is supplied to the engine.

Engine*:* The gas–air mixture is, in turn, supplied to producer gas engine (see fig. 1.10), which converts the chemical energy in the gas to mechanical energy by rotating a shaft. The engine shaft is, in turn, coupled to the shaft of an alternator that converts the mechanical energy into electrical energy. The electrical energy so produced by the alternator is distributed through electrical conductors to the connected load to power the bulbs, motors, and other electrical appliances.

Figure 1.10: The engine, which is a modified diesel engine that generates electricity from the producer gas

1.7 Technical specification of biomass gasifiers

Knowledge of the technical specifications of biomass gasifier systems is vitally important for gasifer operators owing to the variation of these specifications with gasifier type and size. The technical specifications which are important to understand for a system are:

Gasifier design, capacity, model, and make*:* Gasifiers are available in different capacities, and designs. For instance, the gasifier might be a throat-less downdraft model, or an open-top down-draft model. The working principle of the different types is different and should be understood before the gasifier is operated.

Fuel type and preparation: Gasifiers are generally selective with respect to feedstock, with different gasifiers being needed to utilize woody biomass, and agro-residues, for example. The fuel also needs to be dried and reduced to the appropriate size, as mentioned below.

Controlling parameters*:* Fuel size- The fuel size affects the fuel movement within the reactor, as well as the rate of reaction, and the energy intensity per unit volume. Large wood pieces provide a smaller surface area per unit volume of the reactor, which, in turn, affects the quality of gas as volatilization or pyrolysis becomes less intense. Too small a size of biomass leads to an intense volatilization process leading to the formation of significant pyrolytic liquid that is not desirable in gasification. Larger fuel sizes also increase the chances of fuel bridging which hampers smooth fuel movement within the gasifier reactor. Therefore, fuel of one-fourth or one-fifth of the smallest dimension of reactor cross-section is preferred to avoid fuel bridging.

Bulk Density*:* The bulk density of the fuel is also important, as it influences how the fuel is likely to behave during the thermo-chemical processes occurring during gasification. Agro-residues, for instance, have low bulk density, and need to be densified into briquettes before they can be efficiently used.

Moisture Content: Moisture content is another important factor, since with higher moisture content the net calorific value of the fuel decreases, and so does the calorific value of the producer gas, which ultimately reduces gasification efficiency. Also, the tar fraction in the producer gas increases with an increase in the moisture in the biomass. Therefore, the fuel needs to be sun-or oven-dried to reduce the moisture content up to about 20 per cent[3].

Performance parameter: Biomass consumption rate- A gasifier typically consumes a specified amount of biomass per unit of electricity generated (1.2-1.4 kg/kWh), and this value should be known. The gasifier hopper recharged accordingly at appropriate intervals.

Rated gas flow rate: Normally, a gasifier produces around 2- 2.5 Nm^3/h of producer gas per kg of wood fed depending on the properties of the wood and the quantity of air fed. A higher amount of air fed will increase the amount of gas produced, but will reduce the unit calorific value of the gas.

Gas composition: Depending on the gasifier design, wood composition, operation temperature, air flow rate, and other operational parameters, the gas composition will vary somewhat, but is typically CO – 19 ± 3per cent, H_2 – 18 ± 2 per cent, CO_2 –10 ± 3 per cent, CH_4 – 1 ± 3, and N_2 – 45 ± 50 per cent.

Gas calorific value: The calorific value of producer gas depends on the composition, and moisture content, and is generally around 1000-1200 $kCal/Nm^3$.

Gasification temperature: A high fuel-bed temperature (above 800 °C) is preferred to achieve a high carbon conversion of biomass, and low tar content in the resultant product gas. Temperature affects not only the amount of tar formed, but also the composition of tar by influencing the chemical reactions involved in the gasification. High temperature helps in achieving tar cracking under a reducing environment.

Gasification efficiency (hot gas and cold gas): Gasification efficiency can be stated in terms of either hot or cold gas efficiency. The former refers to the efficiency calculated in terms of the gas as it leaves the gasifier before entering the cleaning-cooling system. Therefore, in addition to the calorific value of the producer gas, it also includes the calorific value of the tar, and soot contained in the raw gas, and the sensible energy of all the constituents of the hot raw gas. The cold gas efficiency is calculated based only on the calorific value of the purified and cooled gas, and hence, is lower than the hot gas efficiency. In both cases the efficiency is calculated for the total heat input into the gasifier system.

$$\text{Cold Gas Efficiency} = \frac{\text{Calorific Value of Gas X 100}}{\text{Total heat input (Calorific value of biomass + sensible heat of biomass and air)}}$$

$$\text{Hot Gas Efficiency} = \frac{\text{(Calorific Value of Gas, tar, etc. + sensible heat of gas, tar, etc.) X 100}}{\text{Total heat input (Calorific value of biomass + sensible heat of biomass and air)}}$$

The cold gas efficiency for a gasifier is generally around 70-75 per cent, while the hot gas efficiency can be 85-90 per cent. The technical specifications of different biomass gasifier models commercially available in India, as sourced from the referenced literature, are provided in Table 1 below.

Table 1: Sample (a) -Technical Specifications of a Biomass Gasification System (80 kg/h)

Parameter	Specification
Model	WBG -80
Gasifier type	Downdraft
Type of fuel	Woody biomass
Fuel consumption rate	64-80 kg/h

3 The heat energy contained in the engine flue gas can also be used for drying the feedstock. A description of such a system can be found at <http://cgpl.iisc.ernet.in/site/Portals/0/Publications/InternationalConf/GREEN%20ELECTRICITY.pdf>, while a general description of such systems can be found in the book 'Progress in Thermochemical Biomass Conversion' by A. Bridgewater

Parameter	Specification
Size of fuel	Diameter (Min) – 10mm; Length – 10mm (Max) - Dia. – 50mm; Length – 50mm
Moisture content of fuel	$<$ 20 per cent (Wet basis)
Rated gas flow rate (Nm³/hr)	180
Gas calorific value (Kcal/hr)	$>$1100
Biomass consumption (Kg/hr)	Max 72
Gasification temperature (c)	1050-1100
Gasification Efficiency (%) Hot gas model	$>$85 per cent
Gasification Efficiency (%) Cold gas model	$>$75 per cent
Temperature of gas at Gasifier outlet	300 to 500
Mode	Skip Charger/Manual
Frequency	Every 60 minutes
Ash removal	Ash char removal system
Gas Cooling	Venturi Scrubber/Promiser with water re-circulation
Gas Cleaning	Through proprietary and patented fine filters
Typical gas composition (vol %)	CO_2- 8$\pm$3, CO-19$\pm$3, H_2-18$\pm_2$, CH_4- up to 3, N_2-50

Source: Ankur Scientific Energy Technologies Pvt. Ltd.

Table 1: Sample (b) -Technical Specifications of a Biomass Gasification System (100 kWe)

Parameter	**Specification**
Gasifier Model	100kWe
Gasifier type	Open top downdraft
Size of the feedstock	Cut to sizes up to 60 mm
Moisture of feedstock	10-15 per cent (20 per cent)
Density of feedstock	Over 300 kg/m³
Turn down ratio	4
Lower Gas calorific value	4.6 + 0.2 MJ/kg
Wood consumption rate (Kg/ kWh)	1.0 + 0.1
Typical gas composition (Vol %)	CO_2 - 12$\pm$1, CO - 20$\pm$1, H_2 - 20$\pm$1, CH_4 - 3$\pm$1, and rest N_2

Source: IISc Banglore

Table 1: Sample (c) -Technical Specifications of a Biomass Gasification System (100 kWe)

Parameter	Specification
Gasifier Model	G-100
Gasifier type	Downdraft, throatless[4]
Type of fuel	Woody biomass
Fuel consumption	130 kg/hr
Net Power output	100kWe
Fuel storage capacity	1000 kg
Fuel feeding interval	5-7 hrs
Biomass feeding system	Semi- automatic
Ash removal system	Manual
Turn down ratio	1:3
Blower rating	250 Nm^3/hr with static pressure of 300mm of WG
Auxiliary power consumption	8-10 per cent
Typical gas composition (Vol %)	CO: 22 ± 1, CO_2: 10 ± 1, H_2: 14 ± 1, CH_4: 2 ± 1, N_2: 52 ± 1

Source: TERI

Table 1: Sample (d) -Technical Specifications of a Biomass Gasification System (215 kWe)

Parameter	Specification
Gasifier type	Open top downdraft
Rating	Suitable for 215kWe gross output at generator terminals
Biomass feedstock	Solid biomass with bulk density > 250kg/m^3
Moisture content of fuel	10-15 per cent, ash less than 5 per cent
Lower calorific value (kcal/ Nm^3)	1150-1050
Turn down ratio	1:0.3 (min)
Typical gas composition (Vol %)	CO: 21 ± 1, CO_2: 10 ± 1, H_2: 17 ± 1 , CH_4: 2 ± 1 , N_2: 51 ± 1
Starting time From torching to flaring From torching to supply to the engine	 20 to 30 minutes in the first start & 5minutes in subsequent start 25minutes

Source: TERI

4 In downdraft gasifier, the fuel and air travel downwards towards the grate. In throatless downdraft gasifier, the commonly used throat (conical portion) is eliminated to provide a free fuel flow in the reactor, without any fuel bridging during the gasification process.

Table 1: Sample (e) -Technical Specifications of a Biomass Gasification System (380kWe)

Parameter	Specification
Model	WBG -500
Gasifier type	Downdraft
Type of fuel	Woody biomass
Fuel consumption rate	400-500 kg/h
Size of fuel	Diameter(Min) – 10mm; Length – 10mm(Max) - Dia. – 75 mm; Length – 75mm
Moisture content of fuel	$<$ 20 per cent (Wet basis)
Rated gas flow rate (Nm³/hr)	1125
Gas calorific value (Kcal/hr)	$>$1100
Biomass consumption (Kg/hr)	Max 450
Gasification temperature (c)	1050-1100
Gasification Efficiency (%) Hot gas model	$>$85 per cent
Gasification Efficiency (%) Cold gas model	$>$75 per cent
Temperature of gas at Gasifier outlet	300 to 500°C
Mode	Skip Charger/ Manual
Frequency	Every 12-15 minutes
Ash removal	Dry Ash char removal system
Gas Cooling	Venturi Scrubber/Promiser with water re- circulation
Typical gas composition (Vol %)	CO_2- 8$\pm$3, CO-19$\pm$3, H_2-18$\pm$2, CH_4- up to 3 per cent, N_2-50 per cent

Source: Ankur scientific

Table 1: Sample (f) -Technical Specifications of a Biomass Gasification System (640 kWe)

Parameter	Specification
Model	WBG -850
Gasifier type	Downdraft
Type of fuel	Woody biomass
Fuel consumption rate	680-850 kg/h

Parameter	Specification
Size of fuel	Diameter(Min) – 10mm; Length – 10mm(Max) - Dia. – 75 mm; Length – 75mm
Moisture content of fuel	< 20 per cent (Wet basis)
Rated gas flow rate (Nm^3/hr)	1912.5
Gas calorific value (Kcal/hr)	>1100
Biomass consumption (Kg/hr)	Max 765
Gasification temperature (c)	1050-1100
Gasification Efficiency (%) Hot gas model	>85 per cent
Gasification Efficiency (%) Cold gas model	>75 per cent
Temperature of gas at Gasifier outlet	300 to 5000C
Mode	Skip Charger/Manual
Frequency	Every 12-15 minutes
Ash removal	Dry Ash char removal system
Gas Cooling	Venturi Scrubber/Promiser with water re- circulation
Gas Cleaning	Through proprietary and patented fine filters
Typical gas composition (Vol %)	CO_2- 8±3, CO-19±3, H_2-18±2, CH_4- up to 3 per cent, N_2-50 per cent

Source: Ankur scientific

1.8 Minimum instrumentation to test gasifier on-site

The instruments that are required for analysis of various performance parameters are listed below.

Table 2: Minimum instrumentation to test the performance of a gasifier

Parameters to be analysed		Instrument used
Wood consumption rate		Weighing balance
Energy output (Thermal/Electrical)		Energy meter
Temperature		K type temperature indicator
Pressure (cm of Water Column)		U tube manometer
Biomass	Size of biomass	Vernier scale
	Moisture Content	Moisture meter
Producer Gas	Flow Rate	Venturi-meter
	Gas composition	Gas Analyser
	Total Tar & Particulate estimation	As discussed in Chapter 4

Figure 1.11: A weighing balance is used to weigh the amount of wood fed into the gasifier

Figure 1.12: Moisture meter is used for checking the moisture of the feedstock

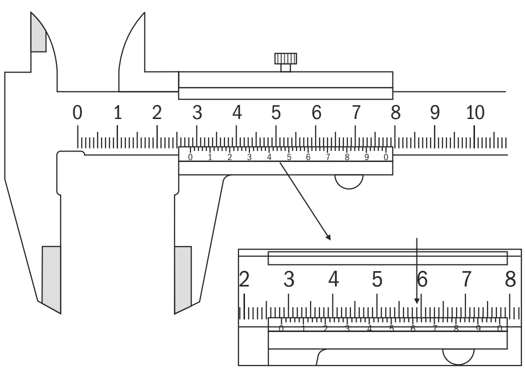

Figure 1.13: A vernier scale is used for measuring the size of the biomass being fed to the gasifier, such as wood chips.

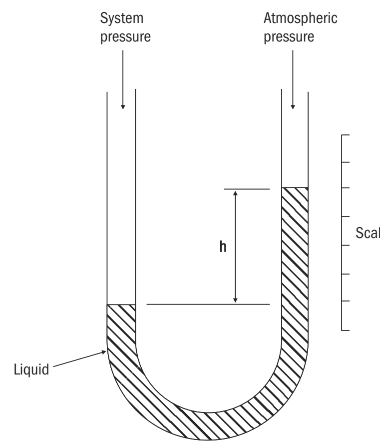

Figure 1.14: A U-tube manometer is a device used for pressure measurement. The difference between the system, and atmospheric pressures can be calculated based on the difference in the heights of the manometer fluid in the two limbs of the manometer, and the density of the manometer fluid.

Figure 1.15: A digital temperature indicator is used for measuring the temperature in different portions of the gasification system. These may be fixed, or portable devices.

Figure 1.16: An online gas analyser is an instrument used for determining the composition of the producer gas. It is connected to the producer gas stream, and gives instantaneous values, unlike other sampling methods which take a long time to give the composition values.

2. Assembly, Erection and Installation: Details and Procedures

Once a gasifier has been designed, and fabricated, proper assembly, and erection of the entire gasification system on-site takes place. It is very important to follow the proper procedure for gasifier installation, as any shortcomings in this area may lead to difficulty in the system operation over the entire life of the plant, and can necessitate expensive and time-consuming changes in the system layout and design at a later stage. The important steps to be followed for the assembly, erection, and installation of downdraft-based power generation systems are given in this chapter.

2.1 Assembly of the gasifier system

Before start of assembling the gasifier system, and other equipment, it is essential to check their proper functioning.

- In the gasifier reactor, place the grate, and assemble the shaking arrangement.
- Further, assemble the gasifier reactor into the ash pit tank.
- Fix the asbestos packaging on the reactor top, and place the hopper carefully on to the reactor flange. Ensure that the hopper is properly placed, and all bolts are tightened uniformly.
- To ensure a leak tight construction, prepare a soap bubble solution and liberally apply to all flange joints, while the air blower is operational. Any leaking flanged joints should be adequately tightened. This applies also to the producer gas transfer pipeline leading to the engine. Before charging wood, fill charcoal over the grate up to the air supply nozzles inside the gasifier reactor. Dry and prepared biomass is then filled in the hopper above the charcoal level, up to the top of hopper so that the feed door can be conveniently closed.
- Assemble all the cleaning, and cooling equipment with the gas line duct with the help of nuts & bolts, ensuring there is no leakage.

2.1.1 Initial preparations/checks

- **Torch preparation:** Prepare the torches using the asbestos rope entwined on mild steel rod of 3-4 mm diameter and about 18 inch length. Dip them in the kerosene oil/ diesel, and light it. Torch should be made ready before the starting of the blower.
- **Ensure size of the biomass**: Biomass should be cut according to the size of the gasifier. Therefore, the fuel size is of one-fourth, or one-fifth of the smallest dimension of the reactor cross-section to avoid fuel bridging. The moisture content of the wood should not exceed 15-20 per cent.
- **Water level**: Check the water levels in the ash pit and in the water seal to prevent any gas leakage.

Figure 2.1: Check water level in the ashpit

- **Engine**: Check the oil level in the engine regularly at the start of the gasifier-based power-generating system, so as to prevent any seizing problem, etc.
- Check the water level in the engine radiator regularly at the start of the system to prevent the rising of the water temperature, etc., which may lead to seizing of engine.
- Check the continuity of the spark in all the spark plugs.

2.1.2 Start-up procedure

- Start the main blower, position the air-valve up to half open, and also keep the flaring port open for at least 5 minutes so that the trapped gases inside the gasifier can be removed easily.
- Shake the gasifier a bit on daily basis with the MS rod, so as to break the gap inside the gasifier that is caused due to the bridging. It makes fuel bed more uniform, and compact.
- Douse the torch with kerosene oil or diesel and then ignite it.
- Open the end-plugs of nozzle, insert the torch into the nozzle position, and plug it back with the end-plugs with a hole, as indicated in figure 2.2.

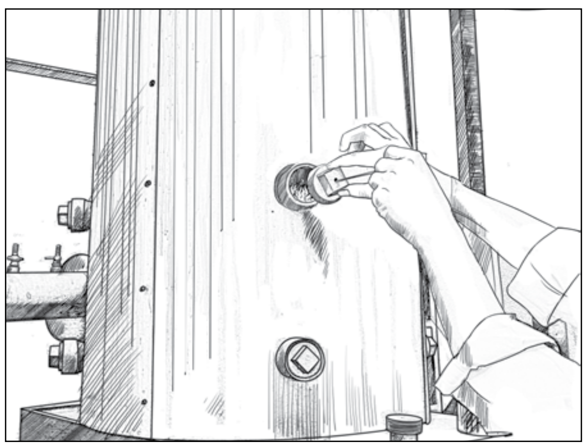

Figure 2.2: Inserting torch to ignite the fuel

- After ensuring a flame in all the nozzles, remove the torch, and close the air nozzles by tightening the end plugs. The end plugs are provided with view glass as it helps in monitoring red fuel condition inside the gasifier box during operation (see fig. 2.3).

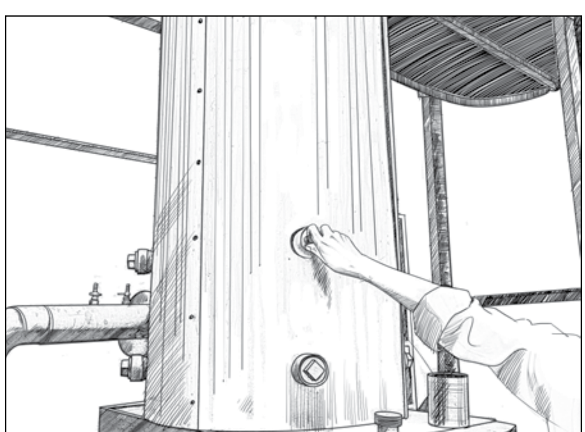

Figure 2.3: Closing of air nozzles by tightening end plugs

In about 5-15 minutes of igniting the fuel bed, combustible gas would start coming out of the gasifier through the flare pipe. The gas can be tested by burning it using a torch. If the quality of gas is good, the gas will continue to burn even after the torch is removed (see fig. 2.4).

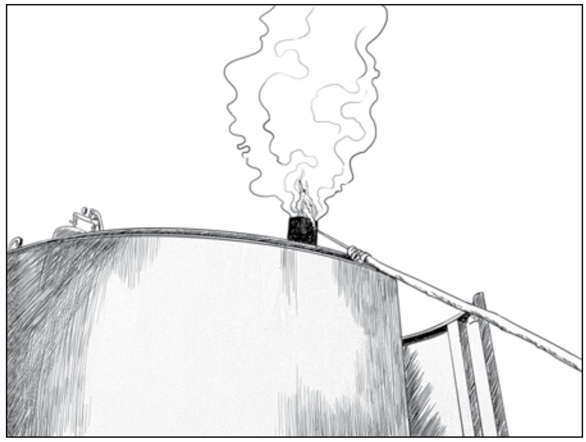

Figure 2.4: Checking the quality of combustible gas by flaring

- Divert the gas towards the gas cleaning, and cooling train using valve operation.
- In order to remove the ash formed on the grate, use the grate shaking rod to shake the grate at regular intervals (20-30 minutes) as shown in Figure 2.5. This also minimizes the chances of any clinker formation in the gasifier bed.

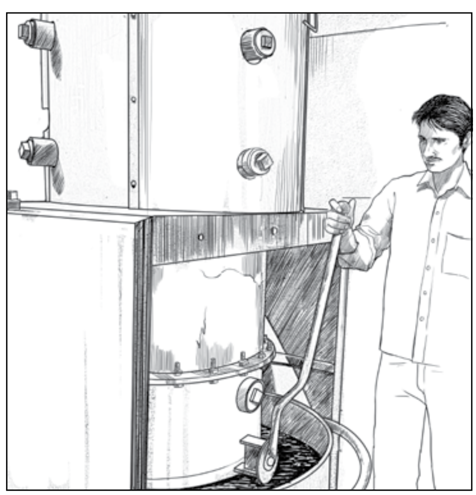

Figure 2.5: Grate shaking to minimize clinker formation

- Start the engine, and open the gas valve at the engine. Observe the frequency meter carefully. Give the load slowly, and increase it gradually. Open the gas-line valve, and simultaneously close the airline valve in a way to maintain the frequency between 48-52Hz.

2.1.3 Shut-down procedure

- Reduce the load on the engine slowly, and then switch off the engine.
- Switch off the air blower connected to the gasifier.
- Open the gas flaring port. This helps in releasing the gas pressure in gasifier, and the entire gas pipeline. It also diverts the gas flow through the gas duct and cooling cleaning train to the flare pipe.

- Then switch off the water pumps.
- Close the engine side-gas valve.
- Shake the grate so that all the ash from the grate gets removed.
- Fill water into the top water seal after the operation of the gasifier (Figure 2.6). It will prevent air entering into the gasifier, and thus avoid the chance of fire inside the gasifier.

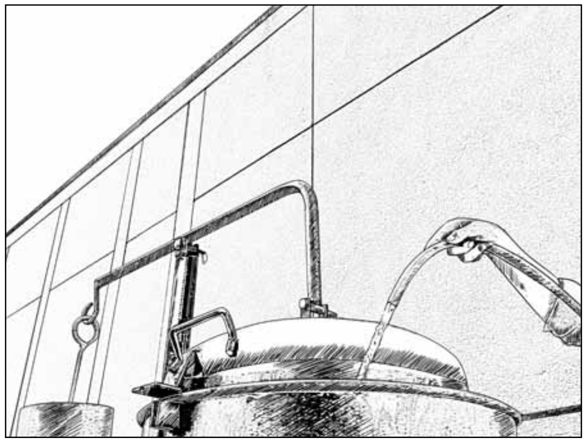

Figure 2.6: Fill water in top seal after operation to prevent entrance of air into gasifier

3. Operation and Maintenance of Gasifier

Following the proper operation and maintenance procedures for a gasifier system is not only important for ensuring the optimal operation, and long system life, but is also necessary from the standpoint of health and safety. This is, therefore, the area where operator training is most critical as any discrepancy can have serious consequences. The major steps involved in O&M of a gasifier are given in this chapter.

3.1 Operation of the gasifier

- *Step 1*: *Fuel charging:* Fill the charcoal initially for the first run till the nozzle height, and then charge the firewood through the fuel charge-door on top of the charcoal till the top of the gasifier in the hopper. The gasifier hopper can hold firewood, which can run the gasifier for about 4-6 hours. It is preferable to charge the firewood in the morning before starting the gasifier, and also check the moisture content, and sizing of the fuel wood carefully before feeding the biomass to the gasifier. Then fill the firewood upto 2 inches from top brim of the gasifier. Do not open the fuel door of the hopper in between the operation for checking the wood level, and do not peep into the gasifier when it is hot.
- *Step 2*: *Filling water in the ash-pit:* Fill the water in the ash pit of the gasifier. The water level has to be 2 inch below the top of the ash-pit wall. Water below this level will result in bubbling of the gas in the ash-pit. So, ensure that the water is filled up to the mark in the ash pit before starting the gasifier.
- *Step 3*: *Filling water in hopper water-seal:* Fill the water in the water-seal/channel provided on the top of the gasifier. This acts as the preventive measure for the leakage of the gas from the top. Water has to be filled up to the position so that it may not tip down from the top of the gasifier. Water level has to be checked every 4 hour and if needed, it could be added. Check the water level always at the start of the gasifier and also before shutting down the gasifier, just to avoid any gas leakage.
- *Step 4*: *Igniting the gasifier:* Switch on the blower, and regulate the airflow to sustain the flame of the torch. Place the torch in the lower ring of the openings/nozzles provided to ignite the firewood in the gasifier. Ignite the wood from at least three nozzles in the lower ring. Red-hot should be seen at all four nozzles. If not done properly, the gasifier will take a lot of time to produce gas, and it may lead to production of a poor quality gas. It may cause backfire problems also. The flaring port should be open during the ignition.
- *Step 5*: *Ignite the gas at flare port:* After ignition of the wood in the gasifier firebox, place the torch at the flare port. Hold the torch till the gas gets ignited, and make sure the flame sustains for 10-15 minutes in the flare-port otherwise the high impurity gas may enter in the system.
- *Step 6*: *Transfer the gas towards cleaning & cooling train:* When the good quality gas starts coming in the flare port, open the valve of the cleaning and cooling train, and close the valve of the flare-port. Allow the gas to pass through the trail so that it can be cleaned as well as cooled before feeding it to the modified diesel engine coupled with an alternator. Ensure the prescribed water flow in the wet scrubbing system for the effective cleaning of the gas.
- *Step 7*: *Feeding gas to the modified engine:* Gradually open the gas-line valve, and simultaneously close the airline valve in a way to maintain the frequency in between 48-52Hz.

- *Step 8*: *Grate shaking:* Shake the grate at every 15 to 20 minutes. The grate shaker has to be handled smoothly and gently. There should be no sudden pull or push, when handling the grate. Shake the grate 3-4 times. Ash accumulation will result into gas bubbling at the fuel door of the gasifier. So bubbling of gas on gasifier top door is an indication of ash accumulation in the gasifier. More ash accumulation in the gasifier results in the reduction of the gas production rate resulting in less power generation output. Therefore, it is important to shake the grate at regular intervals as mentioned.

3.1.1 Running instructions

- Ensure there is no leakage of gas from joints (ensure soap bubble check is used each time any flanged joints are dismantled, and re-assembled), and water seal is continuously topped up. In case of gas bubbling from the water seal, add water.
- Ensure that the grate shaking mechanism is continuously operating, and that there is no pressure build up inside the gasifier, which is indicated by overflow of the water seals.
- Feed proper size of biomass at specified moisture content. This is a very important aspect, since oversize biomass can cause bridging/blockage of the gasifier.
- In order to economically, and safely operate the gasifier, it is preferable that the operator keeps a logbook to record the amount of biomass (and charcoal) which is fed into the system. This will enable the operator to estimate when topping up of fuel is required, and also to gauge the consumption when the gasifier is operating on part load condition. A simple log sheet of biomass topped up vs. time of filling, and the net biomass consumption on hourly basis, preferably maintained in the local language by the operator will suffice for this purpose.

3.1.2 Guidelines for continuous operation

- Charge the firewood every 4 hours, or as per the requirements.
- Keep the water level in the ash-pit, and in the water seals of the gasifier, and venturi scrubber always up to the mark. Add water whenever required.
- Shake the grate at every 15-20 minutes, as per the requirements.
- Remove the ash from the ash-pit at every regular interval.
- Check the water temperature in the venturi scrubber. When the temperature reaches 45°C, open the drain valve, and drain off the water into a water pond, and simultaneously switch on the water pump to fill fresh water in the venturi.

3.1.3 Guidelines for charging during operation

- Ensure that while charging the gasifier, the main blower is switched off, and only suction blower is working.
- Open the lid, or top door of the hopper of the gasifier.
- Charge the fuel-wood pieces of appropriate sizes into the gasifier hopper with the help of buckets.
- Ensure that the wood pieces are dry, and not very big. Use the wood pieces of recommended size.
- Charge the required amount of wood at once to have an easy operation.
- Charge the gasifier at regular intervals of 4 hours, or as per requirements.
- Ensure that there are no wood pieces present in the water seal at the top of the gasifier while charging it.
- Close the gasifier top/lid, and place it so that it sits in the annular groove, or water seal provided on gasifier top.
- Check the water level in the water seal, and if needed, fill it with water.
- Switch on the main blower.
- To re-charge, follow the above steps repeatedly.

3.2 Maintenance of the gasifier

Along with proper operational procedure, regular system maintenance is also required to keep the system in a condition fit for long and continuous operation. There are different types of maintenance required, which can be categorized as below:

3.2.1 Daily maintenance

- Clean ash-pit of the gasifier.
- Clean the heat exchanger by removing the dust collected in it by opening the end-plug from bottom of the heat exchanger.
- Clean the Cyclone Separator by removing the dust collected in it by opening the end-plug from bottom of the cyclone separator.

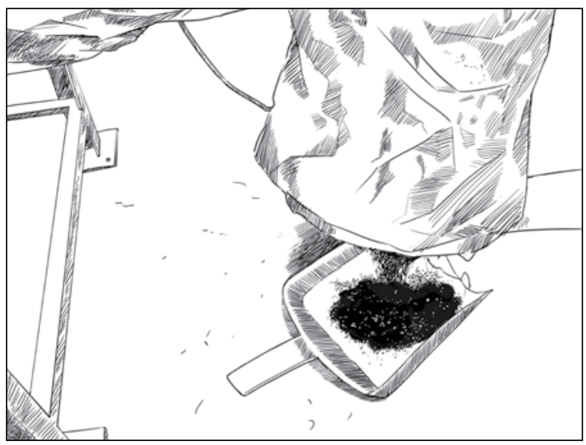

Figure 3.1: Dust removal from Cyclone

3.2.2 Maintenance on every alternate day basis

- Clean the saw dust filters, gravel bed filter, and venturi scrubber ash pit on almost every alternate day. The filter media comprising gravel, saw dust, etc. should be taken out, and sun-dried before filling, and fitting again.
- Clean the water in the ash pit of the venturi scrubber thoroughly.

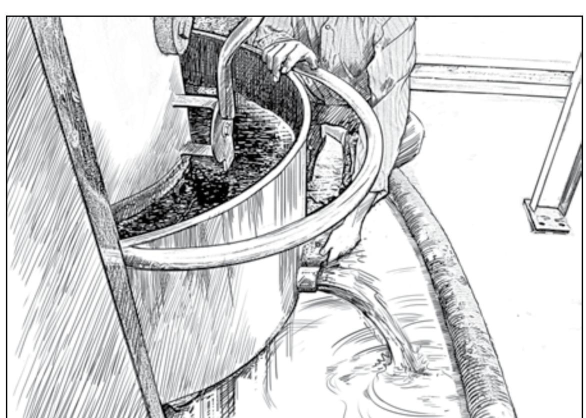

Figure 3.2: Cleaning of ashpit

3.2.3 Maintenance after 200 hrs

- Clean the grate of the gasifier after removing all the wood present in the gasifier if it is there. Clean the gas carrying ducts, and remove all the dust and ash from it.
- Open the different cleaning, and cooling systems installed in the gas line; clean it thoroughly, and fit it back as it is.
- Take out the air-filter from their casing, clean it, and then re-install it.

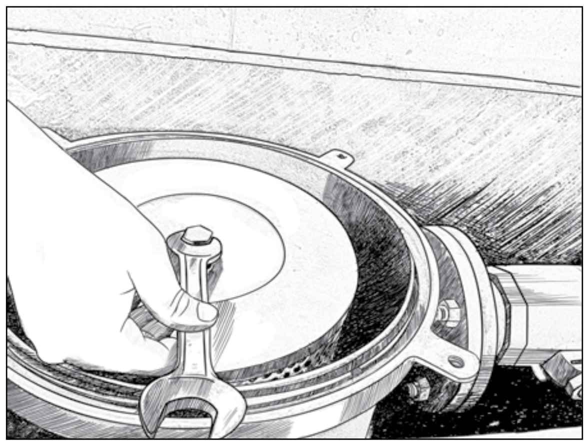

Figure 3.3: Maintenance of cleaning – cooling equipment

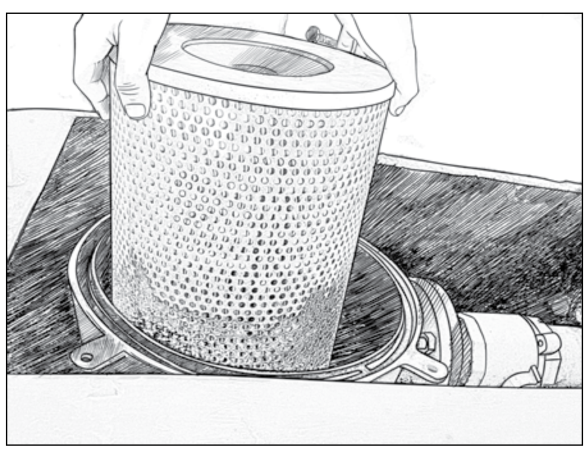

Figure 3.4: Cleaning of cleaning – cooling equipment

3.2.4 Maintenance of cleaning and cooling train

- *Heat Exchanger*: The heat exchanger can be cleaned if the pressure drop across it is raised up to certain limits. Even the inlet and outlet gas ducts can be cleaned at regular time intervals by opening the end-plug at the bottom of the heat exchanger.
- *Cyclone Separator*: The cyclone separator can be removed from the main gas line by opening the nuts & bolts of the flanges with which it is attached. After taking it out, both the cyclone and inlet-outlet ducts can be cleaned, and then can be re-fitted again, or otherwise on daily basis, the end-plug of the cyclone should be opened with the spanner, and re-fitted it again after cleaning.

- *Venturi Scrubber*: The venturi scrubber is made to cool the gas up to the ambient temperature by sprinkling water through nozzle in the main gas line. The water is sprinkled on the gas from the nozzle through a ½hp pump, through a pipeline of 1 inch diameter, that solves two purposes:
- It removes the tar through condensation that gets collected in the water pit itself.
- It cools the gas by exchanging its heat with the duct surface, and water.

The gas cooler does not require much attention as the tar-laden water, which is condensed in the duct is continuously removed at the bottom. But, it is advisable to clean this cooler also when the pressure drop across the cooler is raised up to certain limits. The cleaning of venturi scrubber does not require much attention, but the mesh fitted in the pit to separate the dust particles, etc., should be cleaned after every 4 days to prevent any blockage.

- *Gravel Bed*: The gravel bed is immediately after the venturi scrubber, and is used mainly to remove the moisture carried away by the gas from the venturi scrubber. The principle of the gravel bed filter is separation through impaction. This bed of gravels with approximately 6mm size does not create much pressure drop in the gas line, but needs to be cleaned after every 100 hours. The cleaning can be done after opening the top flange of the filter with ½ inches spanner, taking out the gravels which rest on the mesh. After sun drying, the gravels should be put back in the filter-casing, and then the top flange should be closed with the spanner again.
- *Packet bed filter*: This is a different kind of filter. This filter is used for removing moisture present in the gas. The filter needs maintenance after 100 hours, or if the pressure drops across the filter rises.
- *Fabric Filter*: The final fabric filter, made of synthetic AC filter material with nylon mesh roped over it, is introduced to arrest even the finer dust particles present in the gas stream. It needs to be cleaned at regular intervals of 30 hours, or if the pressure drop across it rises to prescribed limits. For cleaning, the cloth needs to be taken out from the casing, washed properly, and sun-dried before fitting it back to the casing. The water getting condensed here in the filter needs to be drained off on a daily basis.
- Engine maintenance
  - Air intake system.
  - Check for leaks and correct it.
  - Observe the air cleaner restriction indicator.
- Gas pipeline
  - Check for leaks and correct it.
  - Check gas pressure inlet.
- Lubrication system
  - Check for leaks and correct it.
  - Check engine oil level.
  - Check governor oil level.
- Cooling system
  - Check for leaks and correct it.
  - Check coolant level, and top up with pre-mixed coolant, if required.
- Ignition system
  - Check wiring connections are proper.
- Miscellaneous checks
  - Check governor and mixture valve, and gas valve linkages are free.

3.3 Problems in the gasifier

Despite proper gasifier fabrication, installation, operation, and maintenance, it is possible that problems may occasionally arise during the system operation. It is important for the operator to detect these problems at the earliest, and to have the knowledge regarding the proper steps to be taken to address the issue. Some common problems that may arise are given below along with the possible methods for their detection.

- Leakage of gas
  - Peculiar smell
  - Water bubbling in the water seals
  - Visual leakage from ducts, equipment, etc.
- Lean gas
  - During flaring, the flame continuity is not there
  - During operation, if the engine is taking less air from the air valve
- No/Improper flow of gas:
  - No red hot is visible through the gasifier nozzles
  - Pressure drop across any equipment increases
  - No biomass is visible through nozzles due to bridging in the gasifier
- Gasifiers backfire:
  - Blast in the water seals
- Engine mis-firing:
  - Engine unable to start
  - Large variations in frequency if started
  - Irregular combustion noises in the exhaust
- Blockage of ducts or equipment:
  - Pressure drop across ducts or equipment increases

3.4 Troubleshooting

The measures to be taken to correct some common faults in gasifier operation are given in the table 4 below:

Table 4: Some common troubleshooting points for gasifier operation

Fault	Solution
No/Improper gas flow	▪ Check whether the switch is on, or not. If not, switch it on. ▪ Check whether the wood is present in the gasifier body, or not. If not, fill the gasifier with the wood. ▪ Check whether there is any blockage in the gas line. If it is there then clean the ducts ▪ Check before feding of the gasifier that the size of the wood falls in the recommended size, otherwise it may lead to the bridging problem, and hence, improper gas flow. ▪ Check whether the ash accumulation is there in the gasifier, or not. If it is there, do remove the ash from the gasifier by shaking the grate at regular intervals

Fault	Solution
Quality of gas (poor/lean)	■ Check before feeding, whether the wood, which is fed in the gasifier contains the moisture content in the recommended range of10-15 per cent,or not Feed wood with this moisture content only. ■ Check whether the gasifier is ignited properly from all the four nozzles, and red-hot is seen through it from the four nozzles. If not then ignite it properly so that the gas production is adequate, and of good quality. ■ Check whether the grate shaking frequency is not altered from the recommended intervals. It should be not too frequent, or not very delayed, otherwise the gas quality may suffer. ■ Check before feeding to the gasifier that the size of the wood falls in the recommended size, otherwise it may lead to the bridging problem, and hence improper gas flow, and the quality of gas may also suffer.
Leakage of gas	■ If there is some peculiar smell, which creates some headache, nausea, etc., then it is understood that there is leakage of gas. If it is there, do find the gap/hole from which the gas is leaking, and apply some glass-putty to fill that gap/hole. If bubbling of gas is taking place in the water seal below the gasifier, or in the water-seal above the gasifier in the top-door, it shows that the gas leakage is there. To avoid this, fill the water upto the required height so that the gas cannot escape from it.
Backfire	■ If there is any backfire in the system, check first whether there is any leakage through which the system is taking air, i.e., any valve is remained opened, or any holes/gaps are there in the gasifier body, or in the cleaning & cooling train. And if it is there, fill these holes/gaps as soon as possible, and close the valve fully ■ In case of backfire, check whether all the nozzles are ignited properly, and red-hot is seen through all the nozzles. If not then do ignite it properly.
Electrical problems	■ Check whether the switch is in ON position, or not. If not, switch it ON. ■ Check whether all the connections are proper, or not. If not, connect it properly.
No water circulation in cleaning & cooling train	■ Priming of water pumps needs to be done. ■ Check the electrical connections. ■ In last, check the motor winding, whether it needs the repair, or not.
In case the gas is not stabilizing ignition even after 30 min. operation	■ Check that there is uniform view through all inlet air nozzles. If any nozzle does not indicate red-hot glow, re-ignite the same. ■ Check the moisture content of wood for compliance. ■ Check the bridging in the combustion bed through the air nozzles sight, glass-shake the grate to avoid bridging/blockage. ■ Check the gas outlet pipeline for blockage – clean as required.
Bubbling at the ash pit water seal tank	■ Check the water level in the ash pit tank. ■ Check the blockage in main producer gas duct – clean as required.
Bubbling at the water seal (Fuel opening door)	■ Check the blockage in main gas duct, clean as required. ■ Check the water level in water seal. ■ Check the fire wood bed condition.

3.5 Safety measures

Some measures that need to be taken to ensure the safety of operators as well as the equipment are listed below:

- Place a fire extinguisher, of appropriate size, and capacity, on a wall near the gasifier. Ensure that the extinguisher is easily accessible. It is also advisable to install a CO (carbon monoxide) alarm near the gasifier system.
- While charging fuel, do not lean, and look inside the gasifier hopper through the fuel-charging door. Combustible gases can suddenly come out, catch fire, and cause injuries.
- Ensure that the blower is not connected to the electricity supply, and the air supply valves are in closed position while charging fuel inside the gasifier.
- During power cuts, close all air supply valves, and open the gas flare pipe. Close the gas flare pipe after releasing the accumulated gas in the gas duct.
- Do not look at the firebox through the air nozzles with the naked eye when the end-plugs are removed from nozzles. This is because sometimes flames shoot out through them. Use a mirror to see the reflection of the firebox after having removed the end plugs of the nozzles. During regular operation, the red glow in the gasifier reactor can be monitored through the end plugs that have been provided with a view glass.
- While igniting the burner, use a long lighting torch to keep sufficient distance from the burner to avoid any mishap due to accidental backfire. To prevent fire hazards, do not lean towards the burner.
- Prevent gases from accumulating in the burner system. The burner enclosure should be well-ventilated before inserting the lighting torch. Preferably, ignite the torch, and then open the valve that supplies gas to the burner.
- Empty the ash pit tank only after ensuring that the fire in the firebox chamber has been extinguished completely.
- If the body of the gasifier is hot, do not sprinkle it with water to cool it because sudden cooling damages the firebox lining.
- Do not premix too much air with the gas as that can result in gas burning within the gas burner and gas duct. This can cause overheating, and may damage the duct.

4. Performance Evaluation of Gasifiers

4.1 Performance guarantee tests

For any gasifier system, the following performance guarantee tests need to be performed to ensure that the gasifier is in a condition to operate satisfactorily:

- The guaranteed power output of the engine at the site conditions with standard biomass fuel should be comparable with the rated value.
- The maximum auxiliary power consumption should not exceed the stated guaranteed values.
- The specific biomass consumption at the guaranteed power output should be equal to, or less than the stated maximum value.
- The producer gas quality in terms of tar and particulates should be within the permissible limits.
- The gasifier system should be able to meet the specified minimum plant load factor.
- The gasifier system should be able to perform uninterrupted and continuous operation for the specified duration.
- The engine exhaust emissions should be within the limits specified by the appropriate environmental agency.
- The system down-time during continuous operation should be minimum and must be specified by the manufacturer.

Qualifying & acceptable performance levels

As per MNRE, the qualifying, and acceptable performance levels for a biomass gasifier system are as under:

I. Gasification efficiency

- For Woody Biomass- Not Less Than (NLT) 75 per cent (Hot gas); NLT 70 per cent (Cold gas)
- For Rice Husk- NLT 60 per cent (Hot gas); NLT 55 per cent (Cold gas)

II. Tar & particulates

Table 4: Permissible level of tar and particulate for a gasifier

		Naturally Aspirated[a] Engines	Turbo-charged[b] Engines
1)	Tar Content Of Gas	100 mg/Nm^3	25 mg/Nm^3
2)	Particulate Content Of Gas	50 mg/Nm^3	25 mg/Nm^3
3)	Total Tar and Particulate (TTP)	150 mg/Nm^3	50 mg/Nm^3

[a]THT or IIT Bombay Tar Sampling Method [b]IISc Bangalore Tar Sampling Method
These T & P values are as measured at the engine entry point after the cooling-cleaning system.

III. Duration sustainable for uninterrupted continuous operation: NLT 30 hours

IV. Capacity realization: As per manufacturer's specifications

V. Overall efficiency at rated load*

- Woody Biomass, and Electrical Applications- NLT 20 per cent
- Rice Husk, and Electrical Applications- NLT 15 per cent

VI. Engine exhaust emissions: As per Prevailing Norms of Central Pollution Control Board

VII. Availability of the system during the testing schedule

Down Time for any and all reasons cumulatively not more than 5 per cent of the total test duration

** The values will change for other applications as per the efficiency of the corresponding final end use device.*

4.2 Characterization of feedstock

4.2.1 Proximate analysis

Proximate analysis is done to determine the moisture content, volatile matter, ash content, and fixed carbon of biomass, char, charcoal, or any other sample.

- **Collection of biomass sample**: Biomass sample is collected through grab sampling. Grab sampling is done by randomly collected wood pieces from the heaps of biomass. Each lot of biomass is characterized before using for the experiment.
- **Analysis of biomass sample**: The collected sample undergoes following treatment:
- **Moisture Content (MC):** Prior to any treatment, moisture content of biomass is measured by using a drying oven, or by using a commercial moisture meter.
- **Oven-drying method**: The moisture content is determined by drying the weighed amount of sample in an open petri-plate kept at 105°C in an oven. The moisture content of the sample taken as =

$$\frac{\{\text{Weight of Petri plate and sample (B) - Weight of Petri plate and sample after drying (C)}\} \times 100}{\text{Weight of Petri plate and sample after drying (C) - Weight of Petri plate (A)}}$$

- **Volatile matter (VM):** Volatile matter is estimated by heating a known amount of oven-dried biomass sample in an open, and pre-weighed silica crucible at 950 $\pm$ 25 °C for 7 minutes in a muffle furnace. The amount of weight loss in the sample gives the volatile matter of the biomass. It can be estimated as % Volatile matter (dry basis) =

$$\frac{\{\text{Wt. of crucible \& oven dried sample (B) –Wt. of crucible \& sample after heating (C)}\}\text{X100}}{\text{Wt. of crucible \& oven dried sample (B) – Weight of crucible (A)}}$$

- **Ash Content**: Ash Content in biomass samples is estimated by combusting a known amount of oven-dried biomass sample in a pre-weighed, and closed silica crucible at 750 $\pm$ 25 °C for a minimum of 4 hours in a muffle furnace. The amount is estimated as % Ash (dry basis) =

$$\frac{\{\text{Weight of crucible and sample after combustion (C) - Weight of crucible (A)}\} \times 100}{\text{Weight of crucible and the oven-dried sample (B) - Weight of crucible (A)}}$$

- **Fixed Carbon**: The fixed carbon is estimated on material balance basis using equation

% Fixed Carbon (dry basis) = 100 - (% volatile matter + % ash content.)

4.2.2 Ultimate analysis

For the determination of carbon, hydrogen, nitrogen, and oxygen, the ultimate analysis of biomass and oil samples is done using the CHN/O analyser.

Assembly of the CHN/O analyzer

Switch on gases Argon, Nitrogen, and Oxygen and keep pressures as 25 psi, 60 psi, and 20 psi respectively.

a. Switch on the machine, and press 'ENTER' up to PID.
b. Set date, press ENTER till standby mode.
c. System will ask for purge Argon gas, and then press 'Yes'. Enter time for purging as 200 and then press 'ENTER'.
d. A lot of biomass is bulk of biomass. Biomass is purchased in tonnes of wood. When a new bulk of biomass is used, characterization of biomass is done.
e. Then Purge O_2, press Yes, purging time 60 then press 'Enter', purging will be automatic, and finally it will show 'standby'.
f. Press key 'Parameters' and Enter code '12'. Press '1' for furnace 'ON', again press the key 'Parameters' to exit.
g. Wait until Combustion column temperature reaches 925°C, Reduction column temperature 640°C, Detector oven temperature 82.3°C, and signal between 30000 – 350000.
h. Serial No 7 factors can be checked by pressing 'Monitor' Key, and press codes 1, 2, 3, and 5 respectively for each. (After press Monitor key, Enter NO for print list then enter the required codes).
i. After achieving all the temperatures, and signals, one can go for the leak test. Press key 'Diagnostics' for leak test.
j. Press '2' (Gas), Press '1' (Leak test), press code '1', and then 'Enter'. It will take around 5 minutes.
k. After leak test 1 is passed, conduct second leak test. For second leak test Press '2' (Gas), Press '1' (Leak test), press code '2', and then 'Enter'. It will take around 5 minutes.
l. Switch on the PC. Enter the Administrator password.

Double click on the EA 2400 Data Manager icon on the desktop. Enter User name 'Administrator', and then pass word. Enter Parameter code 26 in the instrument then 'Enter'. Press parameter code 40 then 'Yes' again 'Yes'. Press parameter code 41 then press 'Yes'.

Operation of the CHN/O analyser

a. Make three blanks, one conditioner, one blank, and conditioner, blank, three K factors, and blank in the aluminum container provided.
b. Press 'Auto run,' it will show in which sampler we have to add samples.
c. Add blanks, conditioners, and K factors to the auto sampler one by one.
d. After adding blanks press 1(B). After adding conditioners press 3.Name the ID as ACE using respective keys (0.01, 0.03, and 0.05), and add the weight of conditioner also. (The weight of standards and samples should be in between 1.5 to 2 mg).After adding K factors press 2 then press 1(S1) then add weight. Press 'Start'. Wait until the results are coming in the screen.
e. After the calibration, the results of consecutive blanks should be within the range of C $\pm$30, H $\pm$100, N$\pm$16 , and the K factors range C $\pm$0.15, H$\pm$3.75, N$\pm$0.16. Conditioners results should be close to C 71.09 per cent, H6.71 per cent and N 10.36 per cent.

f. After the calibration, the standard can be used as a standard, and compare the results with CHN results of the standard.

g. Sample can be added to the auto sampler in the same manner as standard. Name the samples using respective keys.

h. Ensure that solid samples are powdered nicely to get the uniform results. For oil samples, different containers have to be used.

i. Press 'Parameters' key, enter Code 12, press enter, Press 2 for furnace OFF. Press 'Diagnostics,' press 2 for gas, then press 2 for valve then enter code 4 , press enter, and then press 1 for ON (Pressure release). Again enter code 5, press enter, and then press 1 for ON Press Diagnostics. After reducing temperature, the instrument can be switched off.

4.3 Energy value of feedstock

The heating value or calorific value of any biomass, char, and oil samples can be determined using oxygen bomb calorimeter (Keeping Benzoic acid as standard).

Assembly of the bomb calorimeter

- Prepare a pellet of Benzoic acid using less than one gram of solid. Weigh the pellet accurately, and place in the dish inside the bomb.
- Weigh a six-centimeter piece of ignition wire, and then connect this to terminals inside the bomb as described in the manufacturer's instruction manual.
- Tie up a previously weighed thread on the fuse wire, and put one end of the thread to the weighed sample taken in the sample bottle or container.
- The bomb is placed in the steel receptacle, the top put on, and tightened by hand.
- Fill oxygen in the bomb from the oxygen cylinder to a pressure of 20 atmosphere (Do not exceed 25 atm.) using a channel provided with pressure indicators.
- Assemble the bomb in the steel container, and fill exactly 2000 ml of distilled H_2O in the container using the large graduated cylinder provided for this purpose.
- Check the pressurized bomb for leaks at this point by submerging in the 2-liter beaker of H_2O.
- Connect electric wires to the bomb. Place the top cover on the instrument, and assemble thermometer and stirrer on their positions.

Operation of the bomb calorimeter

- Switch on the instrument and set the rising temperature zero.
- Fire the sample with fire button. Not more than a two second firing time is sufficient.
- Take temperature readings every one-minute for about five minutes.
- Then, after equilibrium is achieved at a new temperature, take two or three post run temperature readings one minute apart.
- Upon completion of the run, remove the bomb, and place it in the steel receptacle.
- Carefully release the pressure by loosening the needle valve on top of the bomb. Clean up the bomb and prepare it for the next run.
- The 2000 ml of distilled H_2O is to be reused for all succeeding runs. Since some loss of H_2O occurs during a run, it is necessary to re-measure and, if necessary, adjust the desired starting temperature using ice.

- The same procedure can be followed for the samples such as biomass, oil, and char.
- Note down the values, and calculation can be made as follows.

Calculations

$$\text{Standard heat of benzoic acid (A)} = \frac{[(6319 \times \text{wt of the benzoic acid}) + (\text{wt of the thread} \times 1000 \times 4.18) + (\text{length of wire} \times 2.45 \times 0.335)]}{\text{Final temperature} - \text{Initial temperature}}$$

$$\text{Calorific value (B)} = \frac{[(\text{Final temperature} - \text{Initial temperature}) \times \text{Standard heat (A)}] - (\text{wt of the thread} \times 1000 \times 4.18) + (\text{length of wire} \times 2.45 \times 0.335)}{\text{Sample weight (g)}}$$

4.4 Thermal characterization of feedstock

For understanding the temperature range in which a biomass gasifier should operate, and the gas yield that can be expected for a particular feedstock thermal characterization of a feedstock can be conducted using a Simultaneous Thermal Analyser (STA).

a. Switch on Nitrogen gas, and keep the pressure as 25 psi.
b. Switch on the chiller attached with the STA. Press the button on the front side to activate it.
c. Switch on the STA.
d. Switch on the PC attached to the STA. Enter the Administrator password.
e. Double click the STA icon on the desktop to launch the software.
f. Remove the lid of the STA sample port, and if present, remove the crucible from the furnace using a pair of forceps.
g. Clean the crucible using tissue paper. Replace the crucible in the furnace, and replace the lid.
h. In the software, click on the icon for taring the in-built balance.
i. Remove the crucible from the furnace, and add a small amount of the sample.
j. In the software, open the method editor window. In the first tab, insert the method name and the file name under which the data will be saved. Go to the third tab, and insert the desired temperature range and heating rate.
k. In the software, press the icon for recording the initial sample weight, if the weight is between 5 and 10mg. If it is more or less than this, the crucible should be removed, and the appropriate removal, or addition of the sample carried out.
l. In the software, click the button for starting the sample run. The curves for weight loss and heat flow will automatically be recorded on the screen as the run proceeds.
m. After the run is completed, wait for the furnace temperature to return to around 50°C.
n. If further runs need to be conducted, repeat steps 6 to 12.
o. Once all runs are finished, close the software, and switch off the PC.
p. Press the button on the front of the chiller to stop it. Subsequently, switch off the chiller and the STA.
q. Switch off the gas supply.

4.5 Quality analysis of producer gas

4.5.1 Estimation of Total Tar and Particulate Matter

The methodology deployed for tar & dust estimation is based on European technical specification (TC BT/TF 143)[5], and TERI's own experimental experiences. Application of the methodology allows determining concentration of gravimetric tar and particles in mg/Nm^3. The repeatability and reproducibility for the results is possible. Measurements are done during stable, and known operating conditions of the gasifier. The characteristic operating conditions during the sampling are recorded. The gas flow rate through the equipment is measured continuously.

Sampling is done for both raw and clean gas. Raw gas sample is taken from the outlet of gasifier. It is untreated gas containing large amount of organic matter and dust particles, whereas clean gas is obtained after cleaning up of raw gas through the cooling-cleaning train. The procedure for collection and analysis of raw and clean gas samples for determination of total tar, and particulates is given in the paragraphs below.

- **Modules of sampling**: A sample train consisting of a heated probe, a heated particle filter (thimble), a series of impinger bottles containing a solvent for tar absorption, and equipment for flow rate adjustment and measurement. The sampling lines including the filter are heated to a temperature of 300ºC to prevent tar condensation. However, to avoid thermal decomposition of organic compounds, the temperature must be properly selected. The description of each of the modules is given below.
  - *Module 1*: The sampling line consists of a sampling probe, filter holder with electrical coils (for heating the apparatus), and temperature controller (to maintain the temperature conditions), and valves. The sampling line should be leak-proof and easy to clean.
  - *Module 2*: Particle Filter: The glass micro fibre particle filter (thimble) of 0.8 micron is used for particle collection. The pretreatment or conditioning of thimbles is done by heating the thimbles approximately at a temperature of 400°C for one hour, and then kept them to acclimatize in a desiccator at room temperature.
  - *Module 3:* Tar Collection Apparatus- Standard glass impingers (100ml or 250ml volume) are used for tar collection. 100 ml and 50 ml of solvent (Isopropanol) for raw, and clean gas respectively is taken in each impinger bottle, first bottle is filled with water and, thereafter, all the bottles are kept in cooling bath as shown in figure. Cooling can be performed by a mixture of ice/salt/water maintaining a temperature of less than 0°C. Isopropanol, as a solvent, is used for the purpose of tar absorption. The required minimum purity is 99 per cent.
  - *Module 4*: Flow meter and Gas Suction pump- The gas flow rate for tar and dust sampling is kept between 0.1 – 0.6 m^3/h, and to maintain this flow rate, a suction pump to suck the sample gas, and a flow meter to read the amount of gas sampled are used.
- **Sampling Procedure:** Prior to sampling a leak test is performed by under-pressurizing the entire sampling train.
- **Leak test**:
  - Firstly, valve of sampling probe is closed (before the particle filter), and gas pump is started. Then, gas bubbles in the impingers, or gas meter readings are detected to observe the possible leakage. If no bubble is observed, the apparatus is leak-proof.
  - A preconditioned filter is weighed using an analytical balance with an accuracy of 0.1mg. Then filter is mounted in the filter holder, and arranged the assembly in the producer gas stream. The filter is heated to maintain a temperature of 300ºC.
  - The gas meter reading and starting time of experiment are recorded. Once the heating temperature is attained, valve of sampling probe is opened. Also the vacuum and timing device are started. Then the control valve is adjusted to give the required flow reading as calculated according to nozzle size, gas velocity, etc. The temperature correction is done using ideal gas equation $V1/T1 = V2/T2$. The control

5 This document TC BT/TF 143 WI CSC 03002.4:2004 (E) been prepared by the technical committee CEN/TC BT/TF 143 "Measurements of organic contaminants (tar) in biomass producer gases". This document is a working document

valve is adjusted throughout the sampling period as required. Also, temperature of cooling bath is checked during sampling so as to maintain the cool temperature of less than 0ºC.

- When an adequate quantity of tar and particles is collected, the sampling is terminated by stopping the vacuum pump, closing the open valve of sampling probe, and stopping the timing device simultaneously. Later, the stop timing, and flow meter readings are recorded.
- When heating apparatus gets cooled, particle filter is dismantled, and kept in desiccator. The content of the impinger bottles is decanted into a dark storage bottle, and kept at a cool temperature (< 5ºC) for later analysis.
- The surfaces of sampling line contacting the gas is washed with isopropanol, and washes are combined with the actual sample for post-sampling analysis.
- Post-sampling procedures and analysis: The samples are analysed in a laboratory. The amount of particulate matter, and tar collected is determined gravimetrically.
- Determination of particle mass: Weight of the preconditioned filter is taken as initial weight (W1). After the sampling, the filter is kept in a desiccator to acclimatize at room temperature, and then weighed. This is the final weight of filter (W2). The mass of particulate matter collected is calculated by subtracting final filter weight from initial weight. The concentration of particles in the gasification product gas in mg/Nm^3 is estimated using the volume of gas sampled.

$$\textbf{Particulate Matter (mg/Nm}^3\textbf{)} = \frac{\{\text{Final weight of thimble(W2) - Initial weight of thimble (W1)}\}\text{x1000}}{\text{Total Volume of gas sampled (V)}}$$

Determination of gravimetric tar mass

The mass of gravimetric tar is determined by means of solvent distillation, evaporation, and further overnight drying as follows:

a. The combined tar solution is used for tar estimation.

b. A standard rotary evaporator with a pressure indicator is used for further analysis.

c. The cool tar solution is acclimatized to room temperature, and decanted the solution into the rotary flask. The flask is connected to the evaporator, and equipment is stared. The water bath temperature is kept at 60ºC, and pressure is maintained at 137 mbar.

d. Once almost all solvent is evaporated, evaporator is stopped; flask is removed, and is left to acclimatize at room temperature.

e. A petri plate is weighed (P1), the left tar solution is poured into the plate, and kept it in oven for overnight drying so as to remove water and isopropanol, if left after distillation.

f. After drying, petri plate is kept in a desiccator to acclimatize to the room temperature and then final weight of

g. ThePetri plate (P2) is taken. The gravimetric tar is calculated in the gasification product gas in mg/Nm^3 by using the volume of gas sampled.

$$\text{Tar Content (mg/Nm}^3\text{)} = \frac{\{\text{(Final weight of Petri plate (P2) - Initial weight of Petri plate (P1)}\}\text{ X 1000}}{\text{Total Volume of gas sampled (V)}}$$

4.5.2 Compositional analysis of producer gas

Gas samples are taken during stable conditions of the gasifier. Sampling is done in both raw and clean gas; raw gas sample is taken from the outlet of gasifier. It is untreated gas containing large amount of organic matter, and dust particles, whereas clean gas is obtained after cleaning up of raw gas through the gasifier train. Further, this cleaned gas is injected into engine for power generation. The collection, and analysis of raw, and clean gas samples for determination of producer gas components is carried out in following steps.

Collection and Analysis of gas samples

Gas samples are collected either in Tedlar bags or by water displacement method in glass bottles. Samples are taken at an interval of two-hours during the continuous running operation. Collected samples are further analysed through Gas Chromatography method.

In Gas Chromatography (GC), Thermal Conductivity Detector (TCD) is used for gas component analysis. Following conditions are maintained in TCD for gas analysis:

- Gas Used in TCD : Argon
- Oven temperature : 40 °C
- Injector temperature : 60 °C
- Detector temperature : 110 °C

The columns used for producer gas detection are Chromosorb 102 and Mol. Sieve 13x. The columns help in detecting all these gases CO_2, H_2, O_2, N_2, CO, and CH_4 respectively.

Gas sampling

- Start the gasifier and make it run for the continuous operation.
- After an operation of 2 hours, gas samples for both raw and clean gas are taken.
- Raw gas sampling is done at outlet of gasifier, whereas clean gas samples are collected after the paper filter.
- Gas samples are collected at an interval of 2-hours during continuous running operation.
- Collected samples are taken to the laboratory for further analysis in GC.
- Gas Analysis: Firstly, TCD and gases are switched on and system is left for achieving the required temperature for gas detection.
- When the temperature is achieved, base line correction is done.
- Now, producer gas standard is taken and 100 µl of standard is injected into the TCD. The standard used is of following compositions: 21.40 per cent Carbon monoxide + 20.25 per cent Hydrogen + 4.89 per cent Methane + 10.15 per cent Carbon dioxide balance Nitrogen
- Area of standard graph is noted.
- The same procedure is repeated with sample gas and area of the sample gas is also noted down.
- The two areas are compared for the estimation of concentration of gas components of producer gas sample. A sample calculation is given below:

Table 5: Sample calculation for GC

Gas Components of producer gas	Area of each component in standard (A1)	Area of each component in sample (A2)	Known Concentration of each component in standard (%) (C1)	Concentration of each component in sample (%) (C2) C2 = (A2/A1)*C1
CO_2	101858	95419	10.15	9.51
H_2	2779930	2728289	20.25	19.87
CO	240703	255211	21.40	22.68
CH_4	178313	38713	4.89	1.06

4.6 Field Measurements

To check the performance of the gasifier, following tests can be done regularly in the field.

4.6.1 Moisture content

Biomass sample is collected through grab sampling. Grab sampling is done by randomly collected wood pieces from the heaps of biomass. Each lot of biomass is characterized before using for the experiment. Moisture content of wood can be calculated in the field using moisture meter.

4.6.2 Bulk Density

Bulk density can be defined as mass of biomass per unit volume of biomass. The bulk density of the biomass can be determined in the field using a bucket of known volume, say 50 liters and then fill it up with biomass samples (wood size that will be used in the respective biomass gasifier system), and then weighing it. The ratio of weight of biomass to the volume of bucket will give the value of bulk density of biomass sample. The values for bulk density will be in Kg/ m3.

4.6.3 Biomass Consumption rate

Biomass consumption rate can be calculated as total biomass consumed during the operation of the biomass gasifier system.

4.6.4 Specific Fuel Consumption (kg/kWh)

Specific fuel consumption (SFC) can be defined as the amount of fuel consumed per hour to produce 1kW power.

$$SFC = \frac{fuel\ flow\ rate\ (\frac{kg}{h})}{brake\ power\ of\ engine\ (kW)}$$

Both, biomass consumption rate and specific fuel consumption can be calculated using weighing balance in the field.

4.6.5 Auxiliary Consumption (kg/kWh)

Auxiliary consumption means the quantum of energy consumed by the auxiliary equipment of the project inclusive of transformation losses from generation voltage to transmission voltage. A significant amount of electricity has to be used to power machinery that is essential to move fuel, air, combustion gases, and water through the process of making electricity in the power plant. This is called auxiliary power. It's the electricity siphoned off by the various pieces of equipment in a power plant in its quest to generate electrical energy.

4.6.6 Plant Load Factor (kg/kWh)

Plant load factor is a measure of the output of a power plant compared to the maximum output it could produce. It can be calculated using equation

$$\text{Plant Load Factor} = \frac{\text{Average output for a given period of time}}{\text{Maximum output}}$$

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