Indira Gandhi National Open University
School of Agriculture

MAM-067
Management of Renewable Energy in Agriculture

Block

3

BIOMASS THERMO-CHEMICAL CONVERSION

Unit 5
Biomass-Based Energy Conversion Technologies 89

Unit 6
Gasification 108

Unit 7
Gasification Systems and Applications 130

BLOCK 3 BIOMASS THERMO-CHEMICAL CONVERSION

Biomass is one of the oldest energy sources known to humankind, yet it continues to be a highly promising renewable resource for the future. In a context of rising energy demand, depleting fossil fuel reserves, increazing prices and growing environmental concerns, biomass-based technologies have regained prominence. Agricultural and rural landscapes in India are rich in crop residues, animal waste, forest residues and agro-industrial by-products. With appropriate conversion technologies, these materials can be turned into heat, electricity, producer gas, biogas and bio-oil. This Block introduces learners to the concepts, processes and applications of biomass-based energy systems, with particular emphasis on thermo-chemical conversion and gasification.

Unit 5 begins with an overview of **Biomass as an Energy Resource and the Major Conversion routes:** physical, biological and thermochemical. Key technologies such as combustion, gasification and pyrolysis are explained along with their working principles and typical applications. Different combustion systems, including fixed bed and fluidised bed designs, are described, and the concept of bio-oil production through pyrolysis is introduced. Improved cookstoves, their design features and contribution to fuel conservation and indoor air quality are also examined to connect technology with household energy needs.

The focus then narrows to gasification as a major thermo-chemical pathway for converting solid biomass into a combustible gas. Learners explore in **Unit 6** the idea of biomass feedstock and its role as an energy carrier, and are introduced to the properties of producer gas and synthesis gas, along with the advantages of using syngas in gas engines. The evolving status of **Gasification Technology** in India and globally is reviewed to highlight its importance in decentralized energy generation and sustainable agricultural development.

Finally, the theory and practice of gasification systems are taken up in greater depth in **Unit 7**. Different gasifier configurations, the process zones within a gasifier, operating parameters, and performance characteristics are discussed. Case studies help learners assess real-world applications, efficiencies and maintenance requirements. Learners are introduced to the operating parameters that influence system performance, as well as gas cooling and cleaning techniques. Through case studies, this unit helps learners assess the efficiency and practical feasibility of gasification technologies. It also discusses safety measures and maintenance practices necessary for the smooth operation of **Gasification Systems**. From an agribusiness perspective, this Unit opens up new avenues for entrepreneurs to explore biomass-based energy enterprises in rural and semi-urban areas.

Overall, this **Block 3** enables learners to develop a clear understanding of how agricultural and organic wastes can be transformed into useful energy through innovative technologies.

The material provided in this Block is supplemented with various *examples* and activities to make the learning process simple and interesting. We have also provided Check Your Progress questions for the self-test at a few places in these units, which invariably lead to possible answers to the questions set in those exercises. What perhaps you ought to do is to go through Units and jot down important points as you read, in the space provided in the margin. This will help you assimilate the content. A list of reference books has been provided at the end of each Unit for further detailed reading.

UNIT 5 BIOMASS-BASED ENERGY CONVERSION TECHNOLOGIES

Structure

5.0 Objectives

5.1 Introduction

5.2 Biomass Conversion Processes/Technologies

- 5.2.1 Physical Processes
- 5.2.2 Biological Processes
- 5.2.3 Thermo-chemical Processes

5.3 Combustion

- 5.3.1 Fixed Bed Combustion
- 5.3.2 Fluidised Bed Combustion Systems

5.4 Gasification

- 5.4.1 Updraft or Counter Current Gasifier
- 5.4.2 Downdraft or Co-current Gasifier
- 5.4.3 Cross-Draft Gasifier
- 5.4.4 Fluidised Bed Gasifier
- 5.4.5 Other Types of Gasifier

5.5 Pyrolysis

- 5.5.1 Type of Pyrolysis

5.6 Bio-Oil

5.7 Cook Stoves

- 5.7.1 Key Design Features
- 5.7.2 Effects on Fuel Conservation

5.8 Let Us Sum Up

5.9 Key Words

5.10 Suggested Further Readings / References

5.11 Answers to Check Your Progress

5.0 OBJECTIVES

After reading this Unit, you will be able to:

- discuss the technology available for the conversion of biomass;
- explain the details design procedure; and
- describe the advantages and limitations of the technology.

ignou THE PEOPLE'S UNIVERSITY

5.1 INTRODUCTION

Energy crises in past and increazing prices of fossil fuels (*i.e.* coal, oil and gas) in recent times have led to a shift to the substitution of renewable energy sources in place of fossil fuels. A considerable effort has been made over the last few years to use alternative renewable energy sources. Biomass is rated as one of the potential renewable sources of energy. Biomass is still used in huge quantities for cooking in villages of the developing world. These fuels, due to their biological origin, are also often referred to as biofuels. The most significant potential sources of biofuels are residues, wood resources from natural forests and biomass from managed plantations. Biomass residues are the organic by-products of food, fibre and forest production.

Biomass can be grown specifically for use as an energy crop. In order to enhance their usage efficiency, these biomass reserves need to be converted by various conversion technologies to more flexible forms like heat, steam or other solid, liquid or gaseous fuels. It is widely estimated that the stored energy in biomass is equivalent to about ten times the world's energy consumption. The most important factor that goes in favour of biomass is its local availability.

In addition to energy security, biomass-based energy technologies offer several environmental and socio-economic benefits. When sustainably managed, biomass energy systems can contribute to reduced greenhouse gas emissions, as the carbon dioxide released during energy conversion is largely offset by the carbon absorbed during plant growth. Biomass utilisation also supports waste management, as agricultural residues, municipal organic waste, and industrial by-products can be effectively converted into useful energy, thereby reducing disposal challenges.

Moreover, the development of biomass energy technologies plays a significant role in rural development and employment generation, particularly in agrarian economies. Since biomass resources are widely distributed, decentralized biomass-based power generation and heating systems can improve energy access in remote and rural areas. With advancements in thermo-chemical, biochemical, and physicochemical conversion technologies, biomass is increazingly viewed as a versatile and reliable component of the future renewable energy mix. Therefore, understanding biomass resources and the associated energy conversion technologies is essential for achieving sustainable and diversified energy systems.

5.2 BIOMASS CONVERSION PROCESSES/ TECHNOLOGIES

Biomass is used for the rural domestic energy requirements (cooking and water heating). The cooking energy requirements are also met from cattle dung, leaf biomass from energy plantations and crop residues.

In comparison to fossil fuels, fresh biomass has certain drawbacks, which are as follows:

- high moisture content that reduces its combustion efficiency
- low bulk density
- lack of a homogeneous physical form

Biomass conversion helps to improve the characteristics of the material as a fuel. The conversion processes largely involve the reduction of the water content and improving the handling characteristics of the material. The energy so obtained can be used for various applications.

In order to exploit the energy content, the biomass is subjected to one of the three conversion processes, namely physical, biological and thermo-chemical. You will learn about these processes in the following sections:

5.2.1 Physical Processes

Physical processes alter the physical state of the biomass to improve its fuel characteristics. Some of these methods are given below :

1) **Particle Size Reduction:** Physical modification, like fabrication into pellets, helps with easy storage and transportation.

2) **Separation:** The separation of feedstock becomes desirable for using its components for different applications. *For example,* the separation of agricultural biomass into food components and residues that may serve as fuel.

3) **Drying:** Drying refers to the removal of all or part of the moisture in the feedstock. Open-air solar drying is one of the cheapest methods.

4) **Fabrication:** Manufacturing pellets by extrusion techniques compacts the feedstock, resulting in uniform combustion of the biomass material.

5.2.2 Biological Processes

The biological conversion processes are essentially of two types :

1) Anaerobic digestion (bio-methanation), and

2) Fermentation-ethanol production.

Biological conversion processes are due to micro-organisms. An *example* of anaerobic fermentation is the conversion of biomass to methane and carbon dioxide in a roughly 2:1 volumetric ratio. The process also yields a *residual digestate or sludge*, which is rich in nitrogen and other nutrients and can be effectively utilized as a *high-quality organic fertilizer*. Anaerobic digestion can be operated under different temperature regimes. The reaction temperature can be in the mesophilic region of 35-37°C or at 55°C for faster thermophilic rates. Depending on feeding and operational strategies, the digestion process may be conducted in *batch, semi-continuous, or continuous modes*. To ensure optimal methane production, the *carbon-to-nitrogen (C/N)* ratio of the input slurry is typically maintained at approximately *30:1*. The process is slightly exothermic, and the ideal *pH range for efficient methanogenesis* lies between *7.0 and 7.2.*

To obtain high methane output, the carbon/nitrogen ratio of the input slurry feed must be approximately 30:1. The process is marginally exothermic, and the ideal pH for rapid methanogenesis is 7-7.2. The primary step in methanogenesis is acidogenesis, in which the input feed (principally carbohydrate) is hydrolysed and fermented to organic acids (mainly acetic) and hydrogen. The acids are then converted by methanogenic bacteria into dissolved methane and carbon dioxide, which finally undergo a transition from liquid to gaseous phase. About 70% of the methane is obtained from acetate.

In alcoholic fermentation, certain types of starchy biomass, such as corn and high sugar crops, are readily converted into ethanol under anaerobic fermentation conditions in the presence of certain yeasts and other organisms. This process forms the basis of bioethanol production, which is widely used as a renewable liquid fuel and as a blending component with conventional gasoline.

5.2.3 Thermo-chemical Processes

Thermo-chemical conversion refers to the alteration of the physical and chemical nature of biomass through heating. Biomass feedstock has unique properties that make it ideal for thermo-chemical conversions, which convert 85-95% of the organic material in the feedstock to liquid and gases with high efficiency. Depending on the conditions used, biomass can be altered very slightly or completely changed.

The three important thermo-chemical processes are combustion, pyrolysis and gasification. These are described in the subsequent sections.

5.3 COMBUSTION

A simple means of converting biomass to usable heat energy is through straightforward combustion, and this accounts for around 90% of all energy attained from biomass.

The carbon and hydrogen in the biomass undergo an exothermic reaction with oxygen to form carbon dioxide, water and heat. The moisture content is a major constraint in the direct combustion of biomass. The higher the moisture content, the more energy is required for the evaporation of water. Several problems associated with the direct burning of biomass can be overcome by the prior conversion of biomass, via gasification or pyrolysis, into better fuels. Dried wood chips, cereal straw, and organic refuse, with heat contents of 18.6-20.9, 16-17 and 10.5 MJ/kg, respectively, are all potential biomass for combustion.

There are several different technologies available that can be used for biomass combustion, and the main ones can be categorised under two headings:

- Fixed bed combustion systems, and
- Fluidised bed combustion systems.

5.3.1 Fixed Bed Combustion

In this method of combustion, air is primarily supplied through the grate from below, and initial combustion of solid fuel takes place on the grate, and some gasification occurs. This allows for secondary combustion in another chamber above the first, where secondary air is added. Fixed bed combustion systems could be further subdivided as:

- Underfeed stokers, and
- Grate firings

Underfeed Stokers

Generally suitable for small-scale systems, underfeed stokers are a relatively cheap and safe option for biomass combustion. They have the advantage of being easier to control than other technologies, since load changes can be achieved quickly and with relative simplicity due to the fuel feed method. Fuel

is fed into the furnace from below by a screw conveyor and then forced upwards onto the grate, where the combustion process begins. Underfeed stokers are limited in terms of fuel type to low-ash-content fuels such as wood chips. Due to ash removal problems, it is not feasible to burn ash-rich biomass, as this can affect the air flow into the chamber and cause combustion conditions to become unstable.

Grate Firings

There are several types of grate firing, with both fixed and moving grates. They have the distinct advantage over underfeed stokers in that they can accommodate fuels with high moisture and ash content, as well as with varying fuel sizes. Fuel must be spread evenly over the grate surface in order to ensure that air is distributed uniformly throughout the fuel and thus combustion is kept homogeneous and stable. There are a number of different types of grate firing, including fixed grates, moving grates, rotating grates and travelling grates.

5.3.2 Fluidised Bed Combustion Systems

Fluidised bed furnaces operate in quite a different manner from fixed bed furnaces and have a number of advantages associated with them. There are two main types of fluidised bed furnaces:

- Bubbling Fluidised Bed (BFB), and
- Circulating Fluidised Bed (CFB).

Bubbling Fluidised Bed (BFB) Furnaces

The fundamental principle of a BFB furnace is that the fuel is dropped down from above into the combustion chamber, where a bed, usually of silica sand, sits on top of a nozzle distributor plate, through which air is fed into the chamber with a velocity of between 1 and 2.5 m/s. The bed normally has a temperature of between 800 and 900°C, and the sand accounts for about 98% of the mixture, with the fuel then making up a small fraction of the fuel and bed material.

BFBs have two main advantages in terms of fuel size and type over more traditional fixed-bed systems. Firstly, they can cope with fuel of varying particle size and moisture content with little problem, and secondly, they can burn mixtures of different fuel types such as wood and straw.

Circulating Fluidised Bed (CFB) Furnaces

If the air velocity is increazed to 5-10m/s, then a CFB system can be achieved, where the sand is carried upwards by the flue gases and a more thorough mixing of the bed material and fuel takes place. The sand is then separated from the gas in a hot cyclone or U beam separator at the top of the furnace and fed back into the combustion chamber, where the whole process begins again.

CFBs deliver very stable combustion conditions, but at an added cost. Due to their larger size compared to other combustion methods, the cost is relatively high, and there are problems involved with fuel size, which must be very small, and the difficulties involved in running them at partial load.

5.4 GASIFICATION

A large number and huge quantities of biomass materials are available from different sectors of the economy. The peat, wood and its wastes, charcoal, agricultural wastes (maize cobs, coconut shells, coconut husks, cereal straws, rice husks, etc.), organic solid wastes from agro industries and solid municipal waste are available and can be used for gasification.

Gasification is defined as the partial combustion of biomass. At elevated temperatures just short of those required for combustion, but in the presence of a limited amount of oxygen or air, biomass can be primarily converted into a mixture of carbon monoxide, hydrogen and volatile hydrocarbons. This process is called gasification, and the objective is, as the name implies, to produce gaseous fuel. It is necessary to ensure complete combustion; otherwise, some tar/char is always formed. Tar is undesirable as it is sticky and corrosive, creating problems in handling and disposal, although a staged gasification/ combustion system solves this problem. Wood and agricultural residues can be used as feedstock for gasification. A typical composition of the gas obtained from wood gasification on a volumetric basis is given in Table 5.1.

Table 5.1: Typical Composition of Gas Obtained from Wood Gasification

Type	Percentage
Carbon monoxide	18-22%
Hydrogen	13-19%
Methane	1-5%
Heavier Hydrocarbons	0.2-0.4%
Carbon dioxide	9-12%
Nitrogen	45-55%
Water vapour	4%

(*TERI*, 1993)

The calorific value of this gas is about 900-1200 KCal/Nm3, and the gas can be used for the generation of motive power either in dual fuel engines or in diesel engines with some modifications (*Kishore*, 1993).

The gasification of solid fuels containing carbon is accomplished in an air-sealed, closed chamber under slight vacuum or pressure relative to the ambient pressure. The fuel column is ignited at one point and exposed to the air blast. The gas is drawn off at the other location.

Gasification is much more environmentally-friendly than landfills, not merely because of its lower net carbon footprint, but because of its lower energy consumption, better recycling efficiencies, increased groundwater safety, and better atmospheric emissions. Every ton of waste that is gasified saves the world from the equivalent of more than 22 tonnes of greenhouse gases that would be produced if that tonne of waste were placed in a landfill. Gasification allows any organic materials in our waste to be reused to produce energy and fuels, avoiding the environmental and political consequences associated with the production and refining of new foreign oil and other fossil fuels.

Depending upon the function and acceptability of biomass gasifiers can be broadly divided into two categories:

- Fixed bed
- Fluidized bed

Depending upon the positions of the air inlet and gas withdrawal with reference to the fuel bed movement, three broad types of fixed-bed gasifiers have been designed and operated. They are called as updraft, downdraft and cross draft gasifiers.

- **Updraft**
  - Forced draft
  - Natural draft
- **Drown Draft**
  - Throat type
  - Throat less (Open core
  - Crossed Draft

5.4.1 Updraft or Counter Current Gasifier

A: Forced Draft Gasifiers

The oldest and simplest type of gasifier is the counter-current or updraft gasifier shown schematically in Fig. 5.1.

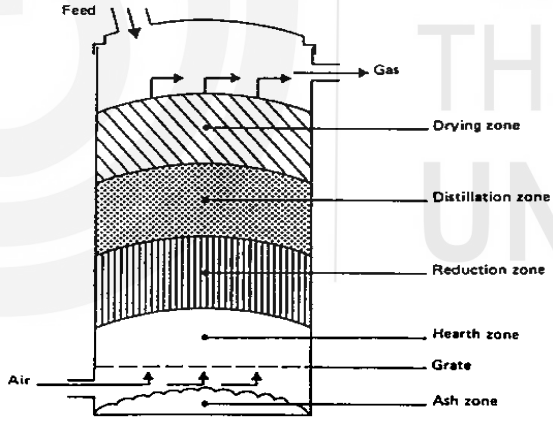

Fig. 5.1: Updraft or Counter Current Gasifier

The flow of air is provided from the bottom, and gas exits from the top of the reactor in updraft gasifiers. Due to the opposite streams of air intake and gas outlet, it is also named a counter-current gasifier. As shown in the figure, the combustion zone or hearth zone is formed just above the grate. The up-flowing hot gases react with downward-falling hot carbon, resulting in the formation of a reduction zone. This zone is formed above the combustion zone. The further decrease in temperature as the gases move up helps in pyrolysing the woody materials and forms a pyrolysis zone just above the Reduction zone. Before leaving the reactor, the hot gases dry the material, which is creating a drying zone in the reactor. The heat is transferred by forced convection and radiation from the lower zones to the upper zones. The tars and volatiles produced during this process will be carried away in the gas stream. Ashes are removed from the bottom of the gasifier.

B: Natural Draft Gasifier

The distinctive feature of the natural draft gasifier is that it operates on the chimney effect without electrical input. These make it ideal for places where there is no electricity or have interrupted power supply. The design of the gasifier is simple and manageable by rural people.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.).

The gases contain high tar, dust and moisture, which are deposited in gas pipelines. The condensation of tar creates severe problems in engine applications. Therefore, gas is to be cooled, cleaned and filtered before using it in engine applications. The latter is of minor importance if the gas is used for direct heat applications, in which case the tars are simply burnt.

5.4.2 Downdraft or Co-Current Gasifier

The tar content in the gas stream can be reduced by modifying the design of the gasifier reactor. The simple solution is to draw the gas from the bottom, so that the reduction zone shifts to just below the combustion zone. The major gas production occurs in this zone. The hot carbon (Pyrolysed coke) is then first passed through the combustion zone, and reactions take place in the reduction zone with hot gases and vapour. Fig. 5.2 shows the direction of flow of air and feed with their possible zones formed in the gasifier reactor.

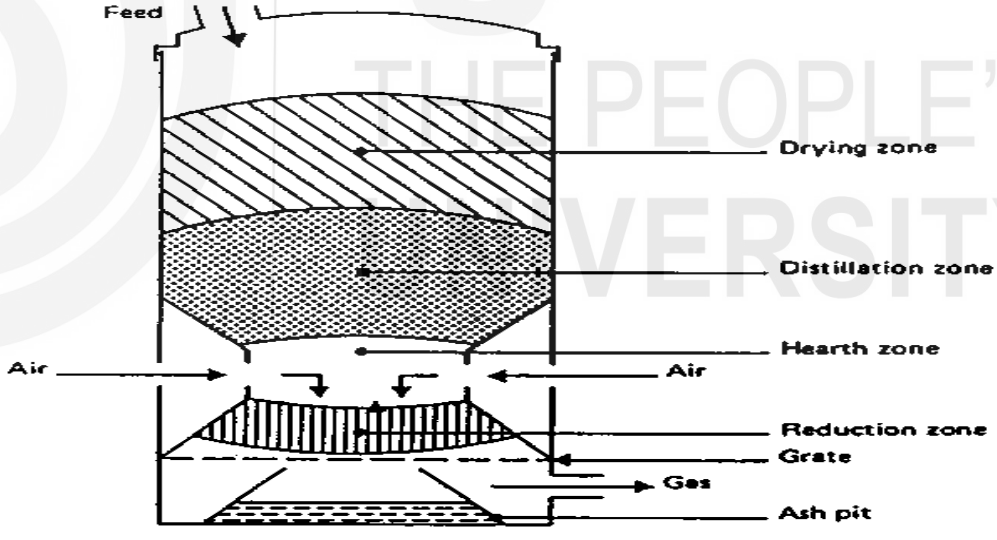

Fig. 5.2: Downdraft or Co-Current Gasifier

Depending on the temperature of the hot zone and the residence time of the tarry vapours, a more or less complete breakdown of the tars is achieved.

The main advantage of the downdraft gasifier lies in the possibility of minimising the tar content in gas, which may be suitable for engine applications. In practice, the tar-free operating turn-down ratios of a factor 3 are considered standard; a factor 5-6 is considered excellent. Because of the lower level of organic components in the condensate, the downdraft gasifier suffers less from environmental objections than the updraft gasifier does.

Downdraft gasifiers also suffer from the problems associated with high ash content fuels (slagging) largely than updraft gasifiers.

5.4.3 Cross-Draft Gasifier

Cross-draft gasifier (Fig. 5.3) is generally considered suitable for low-tar fuels. Here, air enters at high velocity through a single nozzle, inducing substantial circulation, and flows across the bed of fuel and char. This produces very high temperatures in very small volumes and results in the production of low-tar gas, permitting rapid adjustment to engine load changes. The advantage of this type of gasifier is instant starting and simple construction of gasifier.

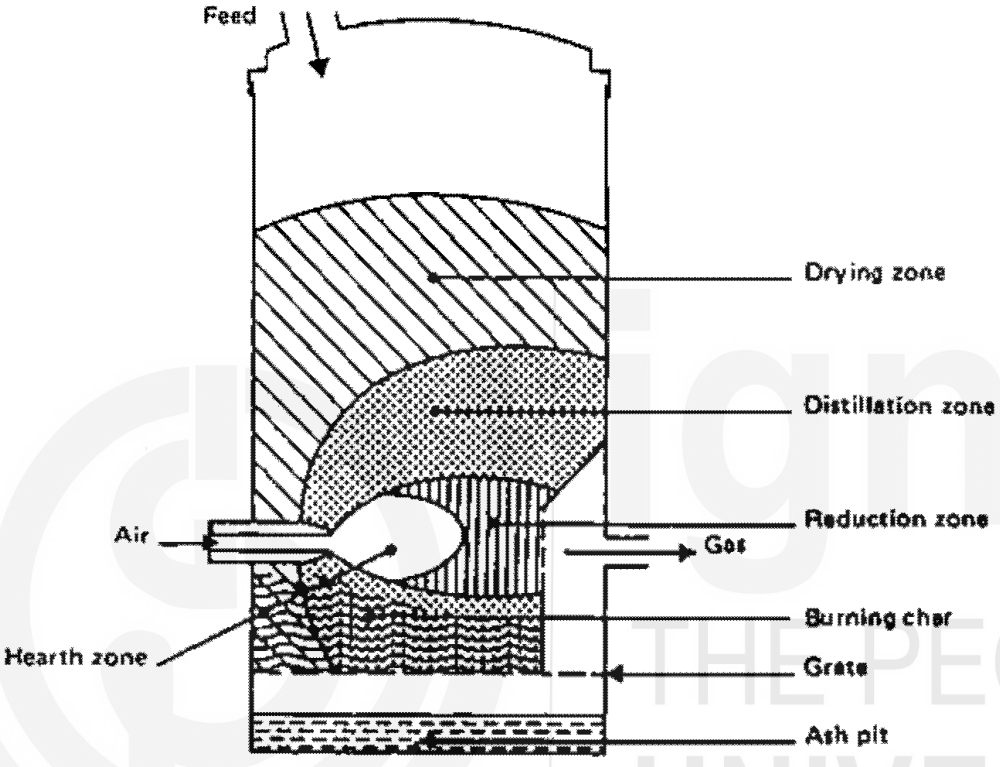

Fig. 5.3: Crossdraft Gasifier

5.4.4 Fluidised Bed Gasifier

The downdraft and updraft gasifiers are highly dependent on the physical, chemical and morphological properties of fuels. The operating problems encountered are of feed flow, slagging and extreme pressure drop, especially in fine mass materials like rice husk, soya husk, etc. The fluidised bed gasifiers are designed to solve these problems, as shown in Fig. 5.4.

Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated, and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material, and almost instantaneously heated up to the bed temperature. Because of this treatment, the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blowout as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

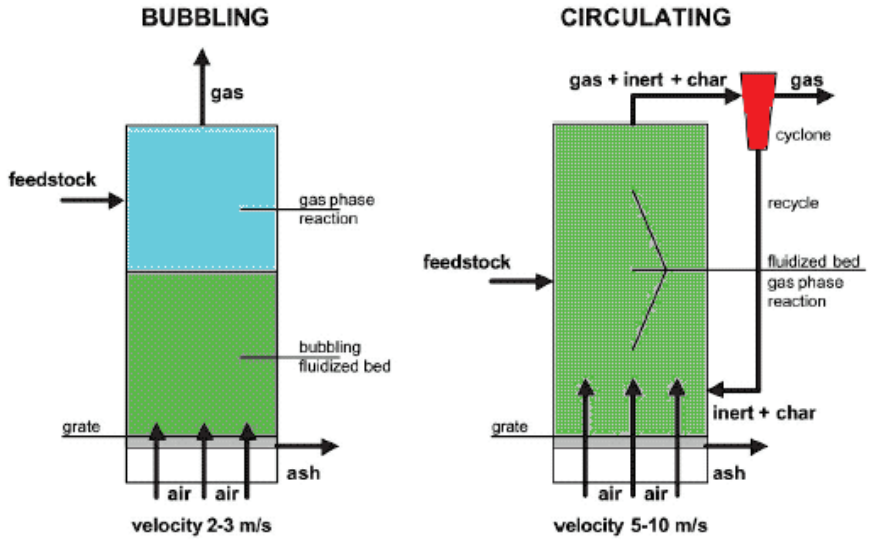

Fig. 5.4: Fluidized Bed Gasifiers

The major advantages of fluidised bed gasifiers are their ability to deal with Fine-grained materials (sawdust, etc.) without the need for pre-processing, as well as easy control of temperature.

The major drawbacks of the fluidised bed gasifiers are their bed stability, the incomplete carbon burnout, and poor response to load changes. Therefore, good control systems are to be incorporated with these gasifiers. The economic feasibility seems to be better in large systems (more than 500 KW).

5.4.5 Other Types of Gasifier

The indirect type gasifiers, double fires, entrained bed and molten bath type gasifiers are developed and tested in the field. The sophisticated equipment and their economic feasibility with size have restricted the use of these gasifiers in the field.

Check Your Progress 5.1

Note: a) Write your answer in the space given below.

b) Check your answer with those given at the end of the unit.

1) How is electricity created with biomass?

.....

.....

2) Observe diagrams or models of fixed-bed and fluidised bed combustion systems. Identify two differences in their operation and suggest one application suitable for each system.

.....

.....

3) Using Table 5.1, identify the two major combustible components in producer gas obtained from wood gasification.

.....

.....

4) Suppose biomass with high moisture and ash content is available. Based on the text, suggest a suitable combustion or gasification system and justify your choice with one technical reason.

.....

.....

5.5 PYROLYSIS

When thermo-chemical conversion of biomass takes place at elevated temperatures but lower than those for gasification (below 600°C), and in insufficient or the absence of air, all three primary products– char, tar and gas can be recovered. The reaction conditions can be so controlled to favour one of these products. *For example,* higher heating rates generally favour tar production at the expense of char and gas. The pyrolysis gas contains carbon dioxide, carbon monoxide, hydrogen, ethane, ethylene and minor amounts of higher gaseous organics and water vapour.

The most common form of biomass pyrolysis is carbonisation, *i.e.* to produce char. Char is superior as a fuel compared to wood or agricultural residues, as its production can be afforded in very simple systems. Chars, besides being easily produced, are more energy-dense than their parent biomass forms and have considerable advantages. Being essentially smokeless fuels, they are mostly used as fuels for cooking and water heating purposes in developing countries.

Under conditions of shorter residence time at higher temperatures (generally not greater than 400°C) and under oxygen-deficient or inert atmosphere, Pyrolysis can also be used for tar production. Tars have undesirable physical properties. They are viscous at ambient temperatures, not completely volatile, exhibit high oxygen content, gummy, corrosive and do not mix with conventional fuels. Fixed bed, moving bed or fluidised bed reactors are used for pyrolysis.

Pyrolysis is a destructive distillation of organic materials in the absence of oxygen, to produce a mixture of solids, liquids and gases. Generally, the heating rate and temperature range of the process decide the production of solid or liquid fuels. Pyrolysis liquid is referred to by many names, including pyrolysis liquid, pyrolysis oil, bio-fuel oil and bio-fuel crude oil, wood liquids and wood oil, liquid smoke, etc. It is combustible and renewable, hence the use of the term "bio", pyrolysis liquid has a heating value of nearly half that of a conventional fuel oil, typically 16-18 MJ/kg.

5.5.1 Type of Pyrolysis

The Main Pyrolysis is of Two Types:

- Slow Pyrolysis
- Fast Pyrolysis

Slow Pyrolysis: It is normally carried out at a low temperature range, 400-600^{o}C and uses mainly the major fuel of charcoal to produce oil and char. Heating rate should be maintained for slow pyrolysis, 5-0^{o}C/min.

Fast Pyrolysis: The major constituents of liquid fuels may be obtained by keeping the temperature of 600°C to 700^{o}C and a heating rate of 5-10 5-10^{o}C/s. Ablative Pyrolysis is a type of fast Pyrolysis.

The fast pyrolysis route offers a more intensive and potentially compact reactor system. In the process of fast pyrolysis material is kept in an inert environment such as nitrogen, and then the required temperature and proper heating rate is achieved to maximize the liquid fraction as a fuel from organic material. The biomass is rapidly heated in the absence of oxygen. As a result, it decomposes to generate mostly vapours and aerosols to the traditional pyrolysis process for making charcoal. Fast pyrolysis is an advanced process that is carefully controlled to give high yields of liquid. The constituents of the output of the fast pyrolysis are given in Table 5.2.

Table 5.2: Constituents of Output of the Fast Pyrolysis

Sl. No.	Process Technique	Product Yield				
		Liquid %	Char %	Gas %	Temperature	Residence Time
1	Fast pyrolysis	75 %	12 %	13 %	600-1000°C	3-5 minutes
2	Slow pyrolysis	25 %	35 %	40 %	400-600°C	30 min.-1 hour
3	Carbonization	30 %	35 %	13 %	400-600°C	30 min. -1 hour
4	Gasification	5 %	10 %	85 %	800-1200°C	1- 2 hours

(**Source:** Philip C. Badger, Renewable Oil International LLC, Florence, Alabama).

5.6 BIO-OIL

Bio-oils extracted from the biomass obtained are also known as pyrolysis oil. Bio-oil and bio-crude for short. Bio-oil is obtained through condensation of hot vapours, which are hydrocarbons, which are included in the biomass in the form of cellulose, hemi-cellulose and lignin. Bio-oil has a smoky odour, is highly viscous, acidic and dark brown in colour, a product of thermo-dynamic equilibrium during pyrolysis, but is produced with short residence times of the reactor and rapid cooling or quenching from the pyrolysis temperature.

Physico-chemical characteristics of bio-oil are given in Table 5.3.

Table 5.3: Physico-chemical Characteristics of Bio-oil

No.	Bio-oil Sources	C (%)	H (%)	N (%)	O (%)
1.	Biomass: garbage Bio-oil	73.6	9.1	4.6	12.7
2.	Acacia Mangium	71.7	6.5	0.4	21.5
3.	Bagassse	73.0	6.8	0.0	20.2
4.	Bagasse Pith	73.8	6.5	0.3	19.4
5.	Banana Stem	74.6	7.3	0.8	17.3
6.	Coconut Husk	73.0	6.1	0.2	20.6
7.	Coconut Shell	70.4	6.4	0.2	22.6
8.	Corn Stalk	72.8	6.1	0.5	22.9
9.	Kenaf	72.9	6.5	0.3	20.6
10.	Oil Palm Empty Fruit Bunch	67.2	7.9	1.1	23.8
11.	Oil Palm Husk	73.5	7.2	1.4	17.9
12.	Oil Palm Petioles	70.4	6.4	0.6	22.6
13.	Oil Palm Shell	79.9	8.1	0.8	11.2
14.	Pineapple Leaf	73.8	7.5	1.9	16.8
15.	Rice Husk	71.8	6.7	0.9	20.6
16.	Rice Straw	73.8	7.4	2.2	16.7
17.	Rubber Tree	73.8	7.4	2.2	16.7
18.	Straw and Stalk of the Rapeseed Plant	57.29	6.63	1.03	34.84

1. **pH Value of Bio-Oil:** The pH value measures the acidity of the derived oil and therefore indicates the corrosiveness of the bio-oil. Biomass-derived oils are known to be highly acidic. The unusual aspect of bio-oils is their carboxylic acid content. Table 5.4 shows the pH value of bio-oil.

Table 5.4: pH Value of Bio-oil

Sl. No.	Bio-oil Source	pH Value of Bio-oil
1.	Sugarcane bagasse	2.7
2.	Rice straw	3.01
3.	Jute stick	2.92

2. **Flash Point:** Flash point is a measure of the liquid temperature necessary for the vapours above a pool of the fuel to ignite by passing a flame through the vapours. This is also a measure volatility of the oil, as well as its ease of ignition. The higher this number, the safer the oil is to handle because the risk of accidental vapour ignition is reduced. Pyrolysis oil often has a reported flash point of between 50ºC and over 100ºC, reflecting a wide variation in the content of volatiles. The flash point of different biomass materials is given in Table 5.5.

Table 5.5: Flash Point of Bio-oil

Sl. No.	Bio-oil Source	Flash Point of Bio-oil
1.	Rapeseed	83
2.	Sugarcane bagasse	> 90
3.	Rice straw	103
4.	Jute stick	> 70

3. **Pour Point:** The pour point is the lowest temperature at which the liquid is observed to flow under prescribed conditions. This parameter is an indication of the minimum temperature at which the oil can be pumped without heating the storage tank. The typical values for the pour points are – 20 to – 28ºC. The pour point of bio-oil is given in Table 5.6.

Table 5.6: Pour Point of Bio-oil

Sl. No.	Bio-oil Source	Pour Point of Bio-oil
1.	Cashew nut shell	–5
2.	Rice straw	–8

4. **Moisture Content:** Moisture content can decrease the heating value of bio-oil and create problems during combustion. Moisture content of bio-oil is in the range of 3-13.8 %.

5. **Ash Content:** Ash is the incombustible material that remains when fuel is burned. Ash is detrimental in combustion processes, in which it lowers the calorific value of the fuel. Excessive amounts of ash can cause high wear in pumps and injectors and lead to deposits in combustion equipment.

6. **Density:** The density of oil is a measure of its aromaticity in hydrocarbon oils, but not in biomass-derived oils. It is a necessary parameter used to calculate the volumetric output of pumps and injectors needed to supply a given rate of delivered energy. The density of the oxygenated bio-oils is much higher, *i.e.* 150 to 1300 kg/m^3, than petroleum-derived hydrocarbon

oils. Unlike hydrocarbon oils, the higher density of bio-oils refers to the high oxygen content. Pyrolysis liquid density varies with time, temperature and water content. The bio-oil, having relatively higher densities, typically has lower water contents. Wood-derived pyrolysis liquid has a density of typically 1200 kg/m^3 for a water content of 25% at 20ºC.

6. **Viscosity:** The Viscosity of oil is an important property since it affects the flow of the liquid through pipelines. The lower the viscosity of the oil, the easier it is to pump and to atomise and achieve finer droplets. The pyrolytic liquid viscosity is highly variable from one liquid to another, depending on the water content, production conditions and whether it is the whole pyrolysis liquid or a recovered fraction. This is the major criterion upon which the oils are graded.

7. **Calorific Value:** The gross calorific value is a measure of the quantity of heat releazed in total combustion and therefore measures the energy content of a fuel. The lower heating value is calculated from the gross calorific value, knowing the hydrogen content in the liquids. Calorific values of the bio-oil are in the range 16.8-31.8 MJ/kg.

Check Your Progress 5.2

Note: a) Write your answer in the space given below.

b) Check your answer with those given at the end of the unit.

1) Does ethanol require more energy to produce than it delivers as a fuel?

.....

.....

2) Using Table 5.2, compare slow pyrolysis and fast pyrolysis in terms of temperature, residence time, and major product yield.

.....

.....

3) Observe the physico-chemical properties of bio-oil given in the tables. Identify **any two properties** that may create challenges during its storage or use as a fuel, and briefly state why.

.....

.....

4) Suppose the objective is to maximize **liquid fuel (bio-oil) production** from biomass. Based on the text, which type of pyrolysis process would you select and why?

.....

.....

5.7 COOK STOVES

About 60-70% of all houses in developing countries remain on non-processed fuels (wood, dung, crop wastes) for their daily cooking and heating needs. The cook stove is the main energy source for about 2.4 billion people around the world and represents 40% of the energy demand in developing countries. A large number of portable wood and biomass stoves have been designed, built and tested over the last decade.

Efforts have been made in recent years to design and promote more efficient stoves. These are known by various names: improved cook stoves, improved stoves, smokeless stoves and wood conserving stoves. These designs work through more efficient burning to reduce smoke, and a chimney or venting to remove that smoke and use less fuel.

5.7.1 Key Design Features

Some of the design features of cook stoves are as follows:

- *Chimney or vent:* to remove smoke outdoors and improve airflow through the fire.
- *Controllable air inflow:* requires the fire to be in an enclosure with an adjustable inlet– allows reduction of burning rate to match needs.
- Use of a material with good insulating properties, for the inside walls of the stove, is usually ceramic.
- Afterburning– mixing the flue (exhaust gas) with a small amount of new air, to allow the last remaining hydrocarbons and carbon monoxide to burn without a flame.
- Use of the flue gas heat for space heating (in cold climates) and/or water heating. To avoid leakage of flue gas into the room, a heat exchanger may be used.
- There is an optimal separation between the pot and the cooker to allow for the airflow to escape. A cook stove may be designed to match the pots and maintain this separation.
- If too much material is placed in the burner, not all of the hydrocarbons will be consumed. So, care should be taken to limit the amount of space for the flammable material.
- As always with appropriate technology, the stoves should be locally constructed with local materials, using local techniques.

Different types of cook stoves available in the markets are given in Table 5.7.

Table 5.7: Types of Improved Cook Stoves

Photograph	Name	Function	Construction Material	Portability	Fuel Type
	Improved three stone or mud-stove	Mono-function	Clay, straw, dung, cement, stone	Fixed	Wood
	Multi-fuel	Mono-function	Metal	Portable	Wood, charcoal, dung, agriculture residues
	Multi-cooker	Mono-function	Metal	Portable	Wood
	Mono-cooker	Mono-function	Metal	Portable	Charcoal
	Mono-cooker	Mono-function	Metal and ceramic	Portable	Charcoal

5.7.2 Effects on Fuel Conservation

Fuel conservation through improved cook stoves appears to be the cheapest way for a nation to invest in new sources of energy. The typical artisan-produced cook stove can conserve about 35% of fuel wood costs.

Improved cook stoves are now considered to be a cost-effective component in reforestation programmes in some countries, and clearly, they have a role to play in improving the quality of life by conserving family resources of cash and time, and reducing smoke in the cooking area.

Improved Stoves Attain High Efficiency by:

- Complete combustion of fuel.
- Maximum transfer of heat of combustion from the flame to the cooking pots and minimum loss of heat to the surroundings.
- This is achieved by incorporating all or some of the following components mentioned below :
- The improved chulha used in India has a sliding firebox door.
- Inlet Grate, Baffles, Dampers, Chimney dampers to control air supply, Cowl– a metal cap attached to the chimney.
- The increazing acceptance of the improved stove shows that stove programmes have positive impacts on users.
- Saving cooking time means more free time and less fatigue, both of which have a direct impact on the time available for other activities and for improving the quality of the kitchen environment.
- Cook stoves, despite being a basic energy technology, have appreciably improved life in the kitchen.

5.8 LET US SUM UP

For the conversion of biomass to energy, a number of technologies are available. However, one has to choose the correct technology depending upon the characteristics of biomass and its end use. Biomass-based technologies are cheaper and economical. Moreover, the raw materials for these technologies are available locally. It also helps in deforestation and improves the ecosystem.

A summary of biomass technologies is given below:

Technology	Conversion Process	Major Biomass	Energy/Fuel Produces
Direct Combustion	Thermo-chemical	Wood, agricultural waste, and municipal solid waste	Heat, steam electricity
Gasification	Thermo-chemical	Wood, agricultural waste municipal solid waste	Low or medium-value producer gas
Pyrolysis	Thermo-chemical	Wood, agricultural waste municipal solid waste	Medium value gas (methane)
Ethanol Production	Bio-chemical (aerobic)	sugar or starch crops wood waste, pulp sludge, grass straw	Ethanol
Methanol Production	Thermo-chemical	Wood, agricultural waste municipal solid waste	Methanol

Biomass can be converted into useful energy through several thermo-chemical and bio-chemical pathways. Gasification converts biomass into producer gas, a combustible mixture rich in carbon monoxide and hydrogen that retains about 70 - 80% of the original energy and can be used for heating, power generation, or converted into liquid fuels such as methanol. Fast pyrolysis involves rapidly heating low-moisture biomass at 450 - 550°C to produce a high yield of liquid bio-oil, which can serve as a synthetic fuel. Anaerobic digestion biologically converts animal waste into biogas, aiding waste management while reducing methane emissions. Fermentation transforms sugars from starch and sugar-rich crops into ethanol through enzymatic action, providing a renewable liquid

fuel. Additionally, methanol production from biomass is achieved through thermochemical conversion of wood and agricultural residues, contributing further to the range of biomass-based energy options.

5.9 KEY WORDS

Biomass: A renewable source of energy derived from organic matter like wood, agricultural waste; also includes algae, sewage and other organic substances that may be used to make energy through chemical processes.

Combustion Efficiency: The actual heat produced by combustion divided by the total heat potential of the fuel consumed.

Energy Plantation (Crops): Energy crops grown specifically for their fuel value.

Fluidised Bed Combustion: A process of burning powdered coal with air or gases; it reduces sulfur dioxide emissions from coal combustion.

Biomass: A renewable source of energy derived from organic matter like wood, agricultural waste; also includes algae, sewage and other organic substances that may be used to make energy through chemical processes.

Combustion Efficiency: The actual heat produced by combustion divided by the total heat potential of the fuel consumed.

Energy Plantation (Crops): Energy crops grown specifically for their fuel value.

Fluidised Bed Combustion: A process of burning powdered coal with air or gases; it reduces sulfur dioxide emissions from coal combustion.

5.10 SUGGESTED FURTHER READINGS / REFERENCES

Biomass Downdraft Gasifier Engine Systems Handbook by T. Read and

- A. Das (Book No. ISBN 1-890607-00-2).
- DOE's Energy Efficiency and Renewable Energy Network.
- S. Kohli, P. Raman and V. V. N. Kishore, Evaluation of Fuels for Gasification, New Delhi.
- Small-Scale *Gas Producer-Engine Systems* by A. Kaupp and J. Goss
- (Book No. ISBN 1-890607-06-10) Cost $ 30.
- Thomas B. Reed and Agua Dass, *Handbook of Biomass Downdraft Gasifier Engine Systems,* March 1988, SERI Publication, March 1988.
- www.eren.doe.gov/biopower.
- http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/t0512e/T0512e00.htm

5.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 5.1

1) Electricity can be generated from biomass in many ways. Direct combustion is the simplest and most common method of capturing the energy contained within biomass. Biomass, when used in boilers to produce steam, can be used either within an industrial process or to produce electricity directly. Gasification is another method to generate electricity from biomass. Instead of simply burning the fuel, gasification captures about 65-70% of the energy in solid fuel (as compared to 20-30% for traditional combustion) by converting it first into combustible gases. This gas is then burned, as if it were natural gas, to create electricity.

2) **Difference 1:** In fixed bed combustion, the fuel remains stationary on a grate and air passes through it, whereas in fluidised bed combustion, fuel particles are suspended and mixed with bed material by high-velocity air.

   Difference 2: Fixed bed systems are suitable for limited fuel sizes and types, while fluidised bed systems can handle fuels with varying sizes and moisture contents.

   Application: Fixed-bed combustion is suitable for small-scale biomass boilers using wood chips. Fluidised bed combustion is suitable for large-scale biomass power plants using mixed or agricultural residues.

3) The two major combustible components in producer gas obtained from wood gasification are carbon monoxide (CO) and hydrogen (H_2).

4) A fluidised bed combustion or gasification system is suitable for biomass with high moisture and ash content because it provides better mixing and uniform temperature, allowing efficient combustion of low-quality and variable fuels.

Check Your Progress 5.2

1) It depends on many factors. Usually, ethanol has a positive energy balance. This is because the energy content of ethanol is greater than the energy used to produce it. This balance is constantly improving with new technologies.

2) **Temperature: Slow:** 400 - 600 °C | **Fast:** 600 - 1000 °C, **Residence time:** Slow: 30 - 60 min | Fast: 3 - 5 min, **Major product:** Slow: Char | Fast: Bio-oil.

3) **Low pH:** Corrosive to tanks and pipelines, **High viscosity:** Difficult pumping and atomization.

4) **Fast Pyrolysis –** high heating rate → high liquid yield.

UNIT 6 GASIFICATION

Structure

6.0 Objective

6.1 Introduction

6.2 Biomass Feedstock

6.3 Biomass Conversion Technologies

- 6.3.1 Physico-Chemical Conversion Technologies
- 6.3.2 Bio-Chemical Conversion Technologies
- 6.3.3 Thermo-Chemical Conversion Technologies

6.4 Thermo - chemical Conversion Processes

6.5 Gasification

- 6.5.1 Concept
- 6.5.2 Process of Gasification

6.6 Properties of Energy Carrier

- 6.6.1 Producer Gas
- 6.6.2 Synthetic Natural Gas (SNG) or Synthesis Gas
- 6.6.3 Advantages of Fuelling Gas Engines with Syngas

6.7 Current Status of Gasification Technology

6.8 Let Us Sum Up

6.9 Key Words

6.10 Suggested Further Readings/References

6.11 Answers to Check Your Progress

6.0 OBJECTIVES

After reading this Unit, you will be able to:

- discuss the sources of biomass;
- explain the importance of biomass gasification in the current scenario of energy requirements;
- describe the thermochemical process that takes place in biomass gasifiers;
- discuss the general properties of energy carriers; and
- explain the current status of gasification technology in India and the World.

6.1 INTRODUCTION

As we know that energy is very necessary for our existence, and it helps with the modernization of our society. Biomass has been one of the main energy sources for mankind forever. It is a renewable energy resource means it is a natural resource that can replenish with the passage of time, either through biological reproduction or other naturally recurring processes. Western and other countries have been developing technologies to use biomass and promote its practical

applications. As a part of the renewable energy programme in India, biomass energy is being considered as an important resource and has been a research focus for a number of institutions within the country. The thermo-chemical conversion process of biomass has been used to meet the energy needs using different technological packages, right from domestic cooking to industrial heat and power. In our country Ministry of New and Renewable Energy (MNRE) is promoting a thermo-chemical process-based technology package. It includes combustion and gasification power generation systems using locally available biomass resources, both in rural areas and as well as in industrial sectors.

6.2 BIOMASS FEEDSTOCK

The biomass feedstock can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. They releaze their stored chemical energy when the bonds between adjacent carbon, oxygen and hydrogen molecules are broken by different processes like combustion, digestion or decomposition. It comprises a wide variety, including not only wood, crops, seaweed, animal wastes, marine plants, fisheries resources, but also pulp sludge, alcohol fermentation stillage, industrial waste, etc. Biomass has always been a major source of energy for mankind. For thousands of years, we burned wood and cow dung to heat our homes and cook our food. Biomass gets its energy from the sun. It is presently estimated to contribute of the order 10 - 14% of the world's energy supply. The total estimated biomass of the world is 1,800 billion tons on the ground and 4 billion tons in the ocean, and a comparative amount of biomass exists in the soil. We can avail biomass energy from different sources as shown in Fig. 6.1.

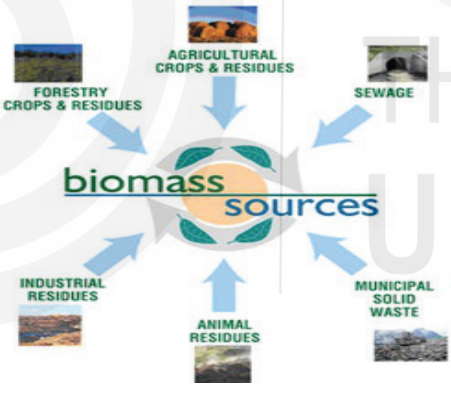

Fig. 6.1: Different Biomass Sources

We know that available energy sources from animals and vegetation are an important resource for developing countries, especially in rural areas. Principal biomass resources are:

- Rural waste (agriculture and animal waste, crop residue, etc.)
- Trees (wood, leaves and forest industry waste)
- Algae and other vegetation from the ocean and the lake
- Urban waste (municipal and industrial waste)

Biomass material may be transformed by chemical or biological processes to produce intermediate bio-fuels such as biogas (methane), producer gas, ethanol and charcoal, etc. Biomass has some advantageous chemical properties, which can be used in current energy conversion systems. Compared to other carbon-based fuels, it has low ash content and high reactivity.

6.3 BIOMASS CONVERSION TECHNOLOGIES

Biomass conversion refers to the process of converting biomass into energy that is used to generate electricity and/or heat. Once a feedstock is obtained, there are a number of technological options available to make use of a variety of biomass as a renewable energy source. There are three general pathways to produce energy from biomass, as shown in Fig. 6.2.

Thermo-chemical biomass conversion processes involve the treatment of biomass under high heat with or without an oxidant. Included in this category are: **pyrolysis, gasification, and combustion.** *Biochemical* conversion processes make use of specific microbial populations to convert biomass resources into high-energy liquid (*e.g.* ethanol) or gaseous compounds (methane). Processes under this category include: anaerobic digestion for biogas production and fermentation into ethanol. Physico-Chemical process is a simple oil extraction from a plant or animal (bio-diesel production).

There are some limitations in each of the processes. The two main limitations in thermal conversions are: (i) moisture content and (ii) ash. In biochemical conversion processes like ethanol production, we have to ensure the sterility of the process so that only the selected microbes are retained. Contamination with other unwanted microbes in the biochemical conversion processes is to be avoided. This will make the reaction proceed with the highest efficiency. We will discuss the different processes in more detail in the following sections.

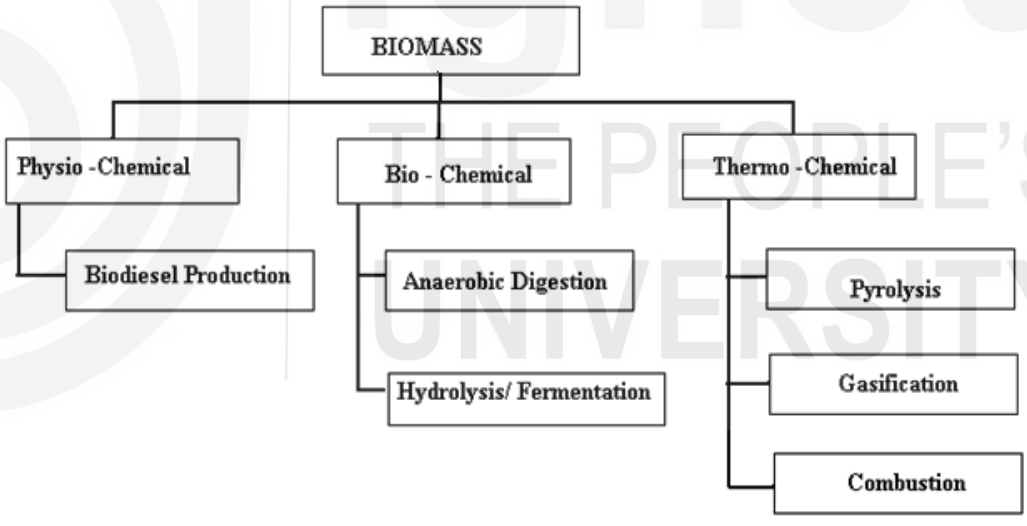

Fig. 6.2: Biomass Conversion Technologies

6.3.1 Physico-Chemical Conversion Technologies

Transesterification (reaction accomplished by the addition of an acid or base catalyst or enzymes (biocatalysts)) of fats and oils is the simplest process of producing liquid transportation fuel from biomass. This is made by mixing refined, bleached, and deodorised vegetable oil or animal fats with an alcohol (generally methanol) in the presence of base or acid catalysts (*e.g.* sodium methoxide). This exposure would yield esters of oil (bio-diesel).

6.3.2 Bio-Chemical Conversion Technologies

Two important biochemical conversion processes are: (1) anaerobic digestion for biogas (CH_4 + CO_2) production; and (2) ethanol (C_2H_5OH) fermentation. These biochemical conversions make use of the enzymes of bacteria and other

microorganisms to break down biomass. In most cases, a microorganism is used to perform the conversion process.

1) **Anaerobic Digestion:** The production of methane from anaerobic digestion of biomass requires the use of acid and methane-producing microbes. Anaerobic digestion (AD) is the process whereby bacteria break down organic material in the absence of air, yielding a biogas containing methane. Anaerobic digestion has been used to process sewage sludge since the 19th century. It is also the natural process that can break down organic material in pools and marshes to produce marsh gas and in landfills to produce landfill gas. The products of this process are:

   - Biogas (principally methane (CH_4) and carbon dioxide (CO_2)).
   - A solid residue (fibre or digestive) that is similar, but not identical, to compost.
   - Liquid liquor that can be used as a fertilizer.

2) **Ethanol Fermentation:** Sugary compounds such as sweet sorghum or sugarcane juices require the use of yeast to produce ethanol, while those coming from starchy materials need enzymes to convert starch into sugar. Conversion of ethanol from biomass resources differs based on the form of substrate used.

6.3.3 Thermo-Chemical Conversion Technologies

Three major thermo-chemical conversion processes are: combustion, gasification and pyrolysis. In brief, we have already covered this in Unit 5. We will discuss it in more detail in subsequent sections.

Check Your Progress 6.1

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) Give various types of pathways to produce energy from biomass.

.....

.....

2) What will be a perfect location to set up a gasifier plant?

.....

.....

3) What is anaerobic digestion?

.....

.....

4) What are the main limitations of the thermo-chemical process? Which is the most commonly used fuel in rural parts of India?

.....

.....

Activity 6.1

Visit a nearby place where a gasifier system is fixed and gather information pertaining to the location. Also, collect information about the start-up and shut-down time requirements for the gasifiers and the quality of required feedstock.

.....

.....

6.4 THERMO-CHEMICAL CONVERSION PROCESSES

As we know that thermal conversion processes use heat as the dominant mechanism to convert biomass into another chemical form. It includes a number of different ways to produce different useful fuels and chemicals from the initial bio-renewable feedstock. Bio-renewable feedstock can be used as a solid fuel or converted into liquid or gaseous forms for the production of electricity, heat, chemicals, or gaseous and liquid fuels. Thermo-chemical conversion processes include mainly three subcategories: pyrolysis, gasification and combustion. Liquefaction is also one of the thermo-chemical conversion processes, but it is less common and not foreseen as a future-oriented technology due to the high operational cost.

Fig. 6.3 shows the biomass thermo-chemical conversion process with its intermediate products and final products.

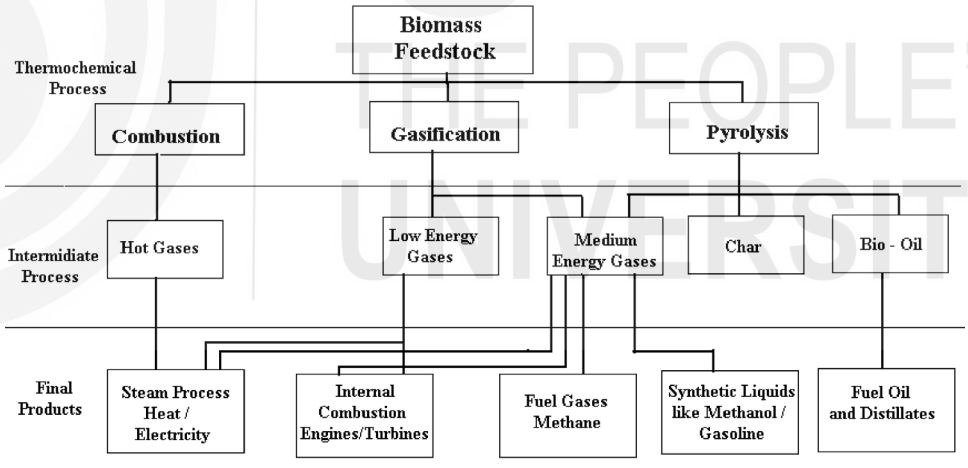

Fig. 6.3: Thermo-Chemical Conversion— Products and their Uses

1) Combustion

Combustion is the process in which flammable materials are allowed to burn in the presence of air or oxygen with the release of heat. The basic process is oxidation. Equation 1 shows general combustion in biomass.

$$CxHyOz + (x + y/4 - z/2)\ O_2 \rightarrow xCO_2 + (y/2)H_2O + Heat \quad (1)$$

2) Gasification

Gasification is a partial oxidation process whereby a carbon source such as coal, natural gas or biomass is broken down into carbon monoxide (CO),

hydrogen (H_2), carbon dioxide (CO_2) and possibly hydrocarbon molecules such as methane (CH_4). The overall equation of gasification is given in Equation 2.

$$C + H_2O + O_2 \rightarrow CO + H_2 + CO_2 + CH_4 \quad (2)$$

3) Pyrolysis

Pyrolysis is the thermal decomposition of organic material in the absence (or limited presence) of oxygen. It involves heating the feedstock to high temperatures (typically between 400°C and 800°C) to break down complex organic compounds into simpler molecules. The main products of pyrolysis are solid char (a carbon-rich residue), liquids (a mix of water, bio-oils, and tars) and gaseous products (H_2, CO, CH_4, CO_2). A simplified representation of pyrolysis is given in Equation 3.

$$\text{Biomass} \rightarrow \text{Char} + \text{Tar} + \text{Gas} \quad (3)$$

6.5 GASIFICATION

Gasification is not a new technology; it was originally developed in the 1800s and is the process used to make town gas for lighting and cooking. During the Second World War, small-scale gasifiers were also used to power internal combustion engine vehicles to overcome the problem of fuel shortages. It is the latest generation of biomass energy conversion processes, and is being used to improve the efficiency and reduce the investment costs of biomass electricity generation through the use of gas turbine technology.

6.5.1 Concept

Gasification is a process that converts carbon-based materials like wood/biomass into combustible gases (CO + H_2) by reacting them with the solid fuel at high temperatures with a controlled amount of oxygen. As we know that thermo-chemical conversion changes the chemical structure of the biomass by means of high temperature, so the gasification agent allows the feedstock to be quickly converted into gas by means of different heterogeneous reactions. Products of the process are very similar to those of the pyrolysis process, as shown in Fig. 6.5. The combustible gas contains CO, H_2, CH_4, H_2O, and trace amounts of higher hydrocarbons, various contaminants such as small char particles, inert gases present in the gasification agent, ash and tars. The amount of oxygen used in gasification is always far less than that used in combustion (typically less than half). In addition to coal, gasification processes can use petroleum coke, biomass, heavy oil, or even natural gas as the feedstock.

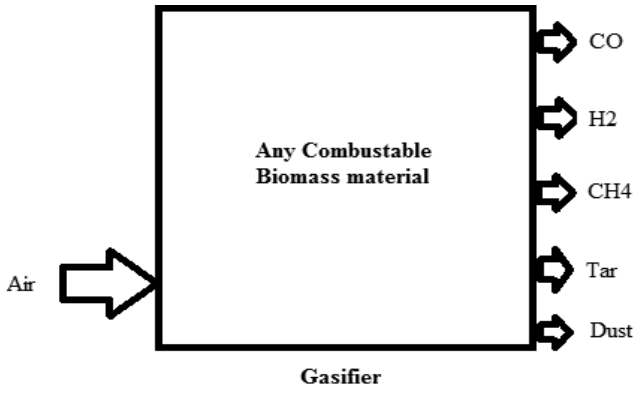

Fig. 6.4: Products of Gasification

The main steps involved in the gasification process can be categorised as upstream processing, gasification and downstream processing, as we describe in Fig. 6.5.

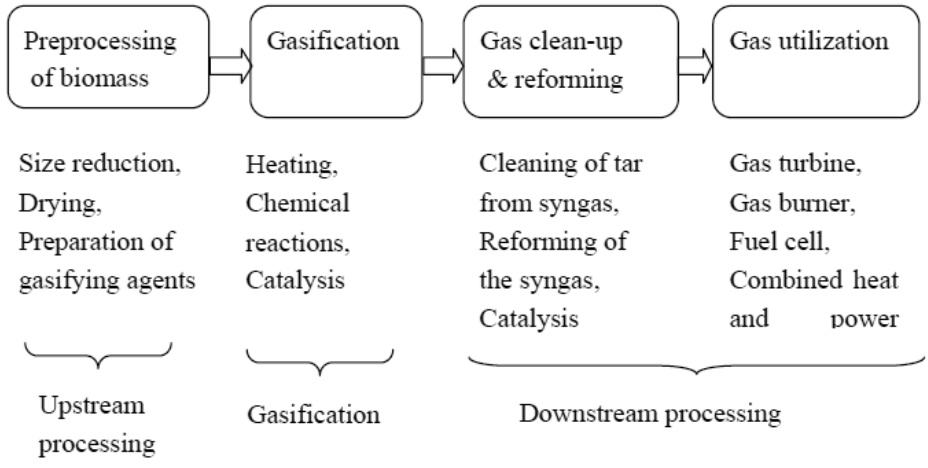

Fig. 6.5: Gasification Steps (processes involved in biomass gasification)

Classification

1) Low Temperature Gasification

If Gasification takes place at relatively low temperatures, such as 700ºC to 1000ºC generates a high level of hydrocarbons compared to high temperatures. Therefore, it may be used directly to be burned via a steam turbine, or it may be used to run an internal combustion engine for electricity generation after suitable gas clean-up.

The combustion chamber for a simple boiler may be close-coupled with the gasifiers, or the producer gas may be cleaned, transported, stored and burned remotely. A gasification system may be closely integrated with a combined cycle gas turbine for electricity generation (IGCC - Integrated Gasification Combined Cycle).

2) High Temperature Gasification

High-temperature gasification is a process in which organic or carbon-based materials (such as coal, biomass, or waste) are converted into syngas (a mixture primarily composed of hydrogen, carbon monoxide, carbon dioxide, and other gases) by subjecting them to high temperatures in a low-oxygen or oxygen-starved environment. This process breaks down the materials at temperatures typically ranging from 700°C to 1,500°C. It can be used to synthesise longer-chain hydrocarbons using techniques such as Fischer-Tropsch (FT) synthesis. If the ratio of H_2 to CO is correct (2:1), FT synthesis can be used to convert syngas into high-quality synthetic diesel biofuel, which is completely compatible with conventional fossil diesel and diesel engines.

Advantages of High-Temperature Gasification

The main advantages of high-temperature gasification techniques are:

- Gasification converts a wide range of feedstocks into usable energy or chemical products, often more efficiently than direct combustion.
- It can convert municipal waste or agricultural residues into valuable products.

- The process produces fewer pollutants compared to conventional combustion, especially if paired with emission control technologies.
- The syngas can be used for electricity generation, heating, or as a precursor for synthetic fuel production (*e.g.,* synthetic natural gas or liquid fuels).
- When biomass or waste is used, gasification can be a more sustainable energy solution compared to fossil fuels.

Applications

After a detailed review of Gasification technology, we can conclude that it can be used for:

- Heating water in central heating, district heating or process heating applications.
- Steam for electricity generation or motive force.
- As part of systems producing electricity or motive force.
- Transport using an internal combustion engine.

Comparison to Coal Combustion (advantages/disadvantages)

Now let's take a look at the difference between coal combustion and coal gasification. Table 6.1 compares the products produced during the combustion and gasification processes.

1. In gasification, because the mixture under gasifying conditions is fuel-rich, there are not enough oxygen atoms available to fully react with the feed. Consequently, instead of producing CO_2, the carbon in the feed is converted primarily to CO, and the hydrogen in the fuel is converted mostly to H_2 rather than H_2O. Both CO and H_2 are excellent fuels for use in a combustion turbine; however, their combustion characteristics are significantly different from natural gas.

Table 6.1: Comparison of the Primary Products Created by the Main Fuel Constituents in Combustion and Gasification

	Combustion	Gasification
Carbon	CO_2	CO
Hydrogen	H_2O	H_2
Nitrogen	NO, NO_2	HCN, NH_3 or N_2
Sulfur	SO_2 or SO_3	H_2S or COS
Water	H_2O	H_2

2. Fuel-bound nitrogen, which is predominantly converted to NOx in combustion, is converted to N_2, NH_3 or HCN in gasification. Both NH_3 and HCN can be removed to very low levels, with the resulting cleaned syngas having essentially no fuel-bound nitrogen.
3. In the combustion processes, sulfur in fuel produces SOx but is converted to H_2S and COS in gasification conditions. With the help of advanced developed technology, both gases, *i.e.* H_2S and COS, can be removed from the syngas.

4. The amount of heat that is released by the chemical reactions is also the major difference between combustion and gasification. In gasification, most of the fuel's chemical energy is not released as heat, but in the combustion process, all of the fuel's chemical energy is released as heat.

6.5.2 Processes of Gasification

In gasifiers, four distinct processes take place as the fuel makes its way to gasification, as shown in Fig. 6.6. They are:

a) Drying of Fuel

b) Pyrolysis

c) Oxidation

d) Reduction

A number of chemical reactions are involved in the gasification process. The following major reactions take place in various zones. Some are exothermic, and some are endothermic.

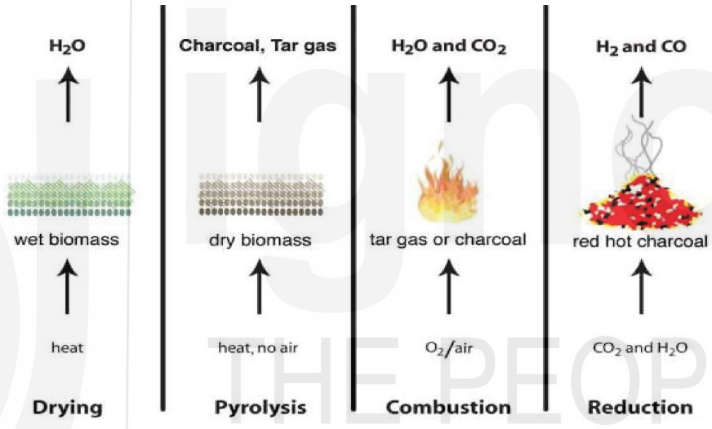

Fig. 5.6: Four Processes in Gasification

1. Drying Zone

In the drying zone, the main process is of drying of fuel. It occurs at around 100°C. Generally, the resulting steam is mixed into the gas flow and may be involved in subsequent chemical reactions.

2. Pyrolysis

This is a process in which tar and other volatiles are driven off. The pyrolysis (or devolatilization) process occurs at around 200-300°C. In this process, volatiles are released, and char is produced, resulting in up to 70% weight loss for biomass. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.

3. Oxidation Zone

When biomass is heated, it releases volatile matter at about 300-600°C temperature leaving fixed carbon. These products burn to form carbon dioxide, water vapour and possibly carbon monoxide depending on the mixture ratio, *in the presence of air*. This is an **exothermic** process releasing energy, which can sustain the pyrolysis and combustion process continuously by transferring heat to the fresh biomass. This process takes place at temperatures of 1200-1400°C.

The main reactions, therefore, are:

$C + ½ O_2 \Longrightarrow CO$ $\quad C + O_2 \Longrightarrow CO_2$ (+393 MJ/Kg moles) (5.1)

$2H_2 + O_2 = 2H_2O$ (- 242 MJ/kg mole) (5.2)

4. Reaction Zone

The hot gases generated in the process, which contain CO_2 and H_2O, further react with the fixed carbon to convert CO_2 to CO and H_2O to H_2. These are **endothermic** in nature and called reduction reactions. Therefore, the temperature is reduced, and the thermal energy is converted to chemical energy stored in CO and H_2 molecules. The process does not proceed until all the CO_2 and H_2O are converted to CO and H_2, since reduction reactions are not favoured below about 600-700°C.

Endothermic

$C + CO_2 = 2CO$ (— 164.9 MJ/kg mole) (5.3)

$C + H_2O = CO + H_2$ (— 122.6 MJ/kg mole) (5.4)

$CO + H_2O = CO + H_2$ (+ 42 MJ/kg mole) (5.5)

$C + 2H_2 = CH_4$ (+ 75 MJ/kg mole) (5.6)

$CO_2 + H_2 = CO + H_2O$ (— 42.3 MJ/kg mole) (5.7)

Reactions (5.3) and (5.4) are the main reduction reactions. Consequently, the temperatures in the reduction zone are normally 800-1000 °C. The lower the reduction zone temperature (~ 700-800 °C), the lower the calorific value of the gas.

After cooling, at the end of the process, the gas composition is 20% CO, 20% H_2, 2% CH_4, 12% CO_2, and the rest being N_2 and equilibrium moisture. After cooling the gas, from about 600°C to ambient temperature, the unconverted H_2O that remains in the hot gases is condensed. The gas may also contain other contaminants, such as carbon dust picked up by the gases flowing past the hot charcoal bed and the residual volatile matter left unconverted during the process, called tar. These contaminants, if not removed, cause difficulty in using the gas in IC engines since they get deposited in various engine parts. Hence, a good gasification system should produce as few of these contaminants as possible and an efficient gas cleaning systems are required to remove the contaminants to the levels acceptable to the end use device.

Check Your Progress 6.2

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) What are biomass gasifiers?

.....

.....

2) How does a gasifier Work?

.....

.....

3) What are the typical effluents of the producer gas?

.....

.....

Activity 6.2

Visit a nearby gasifier plant and gather information about the fluctuation rate in gas quality, gas production and any effect of weather on gas quality.

.....

.....

6.6 PROPERTIES OF ENERGY CARRIER

As we know that the main sources of energy or energy carriers include electricity and heat, as well as solid, liquid and gaseous fuels. These energy carriers occupy intermediate steps in the energy-supply chain between primary sources and end-user applications. Thus, we can say that an energy carrier is a transmitter of energy. Currently, the most important energy carriers are solid (coal), liquid (gasoline, diesel oil, jet fuel, ethanol, methanol, liquefied gases, fatty ester, etc.), gaseous (natural gas, synthetic natural gas, hydrogen), and electricity.

Gasification of biomass to synthesise (producer) gas, mainly CO and H_2, has a relatively high conversion efficiency (40–45%) when used to generate electricity through a gas engine or gas turbine. The gas produced can also be used as feedstock for a range of liquid biofuels. Let us discuss the properties of producer gas and synthesis gas in detail.

6.6.1 Producer Gas

Producer gas is a mixture of combustible (Hydrogen, Methane and Carbon Monoxide) and non-combustible (Nitrogen, Carbon dioxide) gases. The heating value of producer gas varies from 4.5 to 6 MJ/m^3 depending upon its constituents. Similar to syngas, producer gas is also produced by gasification of carbonaceous material such as coal or biomass. When atmospheric air is used as a gasification agent, the producer gas consists mostly of carbon monoxide, hydrogen, nitrogen, carbon dioxide and methane. Table 6.2 shows the properties of producer gas.

Table 6.2: Properties of Producer Gas

Component	Percentage Value
Carbon monoxide	18-22 %
Hydrogen	13-19 %
Methane	1-5 %
Heavier hydrocarbons	0.2-0.4 %
Carbon dioxide	9-12 %
Nitrogen	45-55 %
Water vapour	4 %

Table 6.3 lists the composition of gas produced from various sources. The gas composition is also a function of gasifier design, and thus, the same fuel may

give different calorific value when used in two different gasifiers; therefore, Table shows approximate values of gas from different fuels.

Table 6.3: Composition of Producer Gas from Various Fuels

Fuel	Gasification Method	Volume Percentage					Calorific Value MJ/m^3
		CO	H_2	CH^4	CO_2	N_2	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood with 12-20% Moisture Content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86
Wheat Straw Pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut Husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80
Coconut Shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30
Charcoal	Updraft	30	19.7	-	3.6	46	5.98
Corn Cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice Hulls Pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton Stalk Cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

6.6.2 Synthetic Natural Gas (SNG) or Synthesis Gas

Syngas is always confused with producer gas; however, there is a difference between those two terms:

- Producer gas is the mixture of gases produced at relatively low temperatures (700 to 1000ºC) during the gasification of biomass. It is composed of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and typically a range of hydrocarbons such as methane (CH_4). Producer gas can be burned as a fuel gas, such as in a boiler for heat or in an internal combustion gas engine for electricity generation or combined heat and power. The composition of the gas can be modified by changes in gasification parameters.
- Syngas (synthesis gas) is a mixture of carbon monoxide (CO) and hydrogen (H_2), which is the product of high-temperature steam gasification of biomass. Following clean-up to remove any impurities such as tars, syngas can be used to produce organic molecules such as synthetic natural gas or liquid biofuels such as synthetic diesel or other products, as explained below.

Four main uses of syngas are currently being explored for the production of liquid fuels:

- Fischer-Tropsch synthesis, a chemical catalytic process that has been used since the 1920s to produce liquid fuels from coal-derived syngas and natural gas;
- Mixed alcohols synthesis, a chemical catalytic process that produces a mixture of methanol, ethanol, propanol, butanol and smaller amounts of heavier alcohols;
- Syngas fermentation, a biological process that uses anaerobic microorganisms to ferment the syngas to produce ethanol or other chemicals; and

- Methanol synthesis, also a chemical catalytic process currently used to produce methanol.

Some of the *examples* of syngas production include gasification of coal emissions, waste emissions and steam reforming of coke. It is a gas that can be used to synthesise other chemicals; hence, it is named as synthesis gas, which was shortened to syngas. In these reactions, carbon combines with water or oxygen to give rise to carbon dioxide, carbon monoxide, and hydrogen. The gasification process is used to convert any material that has carbon to longer hydrocarbon chains. One of the uses of this syngas is as a fuel to manufacture steam or electricity.

As we know that gasification generally requires raw materials like coal, petroleum-based materials, or other materials that would be rejected as waste. From these materials, a feedstock is prepared. This is inserted into the gasifier in dry or slurry form. This feedstock reacts in an oxygen-starved environment with steam at elevated pressure and temperature in the gasifier. Finally, the resultant gas (syngas) is composed of 85% carbon monoxide and hydrogen and small amounts of CH_4 and CO_2. The syngas may contain some trace elements of impurities, which are removed through further processing and either recovered or redirected to the gasifier. If the gasification product contains a significant amount of non-combustible gases such as nitrogen and carbon dioxide, the term used for such mixtures is *Producer Gases*. The energy contents of producer gas, syngas and natural gas are shown in Table 6.4.

Table 6.4: Typical Energy Contents of Producer Gas, Syngas and Natural Gas

	Energy Content	
	MJ/m^3	**Btu/ft^3**
Producer Gas	2.5 to 8	65 to 220
Syngas	10 to 20	270 to 540
Natural Gas	38	1028

Properties of Contaminations: Carbon monoxide is produced from the reduction of carbon dioxide. Its octane number is 106, but its burning velocity is low. It is very toxic in nature. Hydrogen is also the product of the reduction process in gasification. Its octane number is in the range of 60-66, but its burning velocity is very high. Hence, it increases the burning velocity of producer gases. Methane and hydrogen are mostly responsible for the high heating value of the gases. Nitrogen and carbon dioxide are noncombustible gases in the producer gases. A high percentage of carbon dioxide indicates incomplete reduction inside the gasifiers. The main properties of hydrogen gas are given in Table 6.5.

Table 6.5: Main Properties of Hydrogen

Gas Density	0.0899 kg/Nm$_3$
Liquid Density	70.99 kg/m$_3$
Boiling Point	20.4 K
Melting Point	14 K
Lower Heating Value (LHV)	121 MJ/kg
Burning Range	4 - 74.5 % volume

6.6.3 Advantages of Fueling Gas Engines with Syngas

- Independent power supply.
- Reduced energy costs and greater predictability and stability.
- Efficient and economic combined heat and electricity supply.
- High electrical efficiency compared to other power generation technologies (*i.e.* steam or gas turbines).
- Best suited for an electrical output range from a few hundred kW to 20-30MW.
- Low gas pressure required.
- Substitute for conventional fuels.
- Environmental benefits from greenhouse gas reduction.

6.7 CURRENT STATUS OF GASIFICATION TECHNOLOGY

The biomass gasification market size reflects the overall market value of biomass gasification systems that convert feedstocks, including wood chips, agricultural waste, and municipal solid waste, into a clean-burning fuel gas. Biomass gasification serves as a sustainable alternative to fossil fuels, diminishing greenhouse gas emissions and fostering energy independence. The global biomass gasification market is projected to attain a value of US$113.9 billion in 2024, with a compound annual growth rate (CAGR) of 9%, culminating in a market worth of US$270.7 billion by 2034. This expansion is propelled by increazing environmental apprehensions and diminishing fossil fuel reserves. The increasing focus on renewable energy, climate change mitigation, and reduced dependence on fossil fuels are primary catalysts for this market growth.

Countries like as India, the United States, China, and Brazil have made substantial advancements in the adoption and expansion of biomass gasification technology, facilitating the shift towards cleaner energy systems.

Biomass gasification is a technique that transforms organic resources into a gas suitable for energy generation. Syngas can be combusted to generate heat or power, or it can be utilized to produce liquid fuels such as diesel or ethanol. The global gasification capacity is steadily increazing. Unfortunately, amidst global activity, the economic impact of gasification technology so far has been minimal and significantly less than that of other renewable energy sources, including solar and wind. Gasification is a recently revitalized technology, and much of its progress remains in the learning phase. Biomass gasification technology has made substantial progress worldwide, with many firms aiding its evolution. Prominent firms in the sector include SynTech Bioenergy (USA), ANDRITZ (Austria), Valmet (Finland), Ankur Scientific Energy Technologies Pvt. Ltd. (India), Chanderpur Works Pvt. Ltd. (India), OVN (India), and Infinite Energy Private Limited (India). These firms constitute a segment of the global biomass gasifier manufacturing sector, reflecting the extensive interest and investment in this sustainable energy technology.

Biomass gasifiers are essential for enhancing energy accessibility in rural and off-grid regions, especially in developing nations. These systems can be

implemented locally to supply electricity for lighting, water pumping, and minor industrial operations, presenting a sustainable energy solution in areas with inadequate infrastructure. Off-grid biomass systems can enhance quality of life, promote economic development, and diminish dependence on expensive and environmentally harmful kerosene or diesel generators.

- ***LARGEST BIOMASS GASIFIERS WORLDWIDE***

Biomass gasification is mainly used in pilot and demonstration plants at a few large industrial-commercial scale and operational units. We know that gasification is a process that converts organic or fossil-based carbonaceous materials mainly into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion in a controlled amount of oxygen and/or steam. The largest biomass gasifiers found in the world are listed in Table 6.6. Gasifiers that use waste as feedstock have also been noticed in this list because of the small number of operating large-scale gasifiers.

Table 6.6: Some Largest Biomass Gasifiers in the World

S. No.	Plant Name	Location	Capacity	Feedstock	Technology	Purpose
1.	Vaskiluoto Biomass Plant	Vaasa, Finland	140 MW	Wood-based biomass	Biomass gasification	Integrated with a coal plant for electricity and heat
2.	GoBiGas Project	Gothenburg, Sweden	20 MW (Phase 1) 100 MW planned	Forest residues	Biomass gasification	Biogas production
3.	Chemrec Plant	Pitea, Sweden	3 MW demo plant	Black liquor	Black liquor gasification	Pulp and paper by-product processing
4.	Elcogas Puertollano IGCC	Puertollano, Spain	320 MW	Biomass, coal, refinery residues	IGCC (Integrated Gasification Combined Cycle)	Electricity generation
5.	Vaskiluodon Voima Oy	Vaasa, Finland	140 MW	Wood, forest residues	Biomass gasification	CHP plant integration
6.	Metso Biomass Plant	Vaasa, Finland	140 MW	Wood, forest residues	Biomass gasification	CHP plant integration
7.	Iowa State University CHP Plant	Iowa, USA	30 MW	Biomass (corn stover)	Biomass gasification	Campus heat and power

The largest operational gasifiers use mainly wood-based feedstock, like forest residue, bark, waste wood and wood pellets. The status of gasification at the country level depends on the background of industry and energy production in the country. In countries where gasification has been most used because of widespread forest or pulp, paper industry and ample indigenous biomass. Gasifiers are currently used for co-firing purposes, for power production using gas engines and for fuel and chemicals production. There are ambitious plans for large-scale (more than 100 MWth) facilities for renewable diesel, ethanol and SNG production.

In India:

The Government of India (GoI) has recognised the potential and significance of biomass energy and has implemented a number of programmes through MNRE to promote the development of efficient technologies for its application in a variety of sectors of the economy, thereby ensuring that the maximum benefits are derived. MNRE has implemented bagasse-based cogeneration in sugar mills and biomass power generation under the biomass power and cogeneration programme to optimize the utilization of biomass. In order to promote the application of technologies for the production of advanced biofuels, the Government of India revised its national biofuel policy in 2018. This policy aims to utilize, develop, and promote domestic feedstock for the production of biofuels, thereby substituting fossil fuels and contributing to the mitigation of climate change, as well as creating new employment opportunities in a sustainable manner. This policy incorporates a variety of biofuels that can be used as transportation fuel or in stationary applications, such as bio-ethanol, bio-diesel, bio-CNG, advanced bio-fuels, and drop-in fuel. Agriculture is the primary source of sustenance for approximately 58% of India's population, as the country is an agrarian economy. India produces an abundance of organic waste that can serve as feedstock for contemporary bioenergy production. At present, only a small portion of this sustainable feedstock has been utilized.

India, which is the world's second-largest producer of sugar cane, also generates enormous quantities of bagasse, an energy-rich byproduct of sugarcane refining. The annual production of bagasse in India is approximately 87 MT. Bagasse-based cogeneration has the potential to generate nearly 14 GW of power in India.

A variety of biomass residues, including agro-residue, shells, husks, de-oiled cakes, and wood, are being utilized for ethanol production in India, where biomass-based energy generation has been steadily increazing. Combustion (Rankine Cycle), bagasse-based cogeneration, non-bagasse-based cogeneration, gasification (Otto Cycle), and other advanced biofuels technologies, including cellulosic ethanol, trans-esterification, and biomethanation, are among the technologies that are currently being pursued for the deployment of bioenergy in India. Using biomass combustion and gasification technologies, approximately 11 GW of biomass power and cogeneration facilities were established in India, primarily to address local heat and power needs. Nearly 8 GW of electricity generation in India is generated by bagasse-based cogeneration plants that employ direct combustion. At present, India has two operational cellulosic ethanol plants, one of which is a pilot plant and the other is a demonstration plant. These plants have a combined capacity of 1.75 million litres of ethanol per year. Numerous additional cellulosic ethanol facilities are currently in the development phase. The Government of India has been emphasising the expansion of bio-diesel production in India. In 2019, India's bio-diesel production capacity was approximately 670 million litres. In India, a cumulative total of 50.28 lakh small-scale biogas plants and 389 medium-scale biogas plants were established for the generation of electricity or the use of biogas for a variety of thermal and cooling applications. The cumulative capacity of medium-sized biogas facilities in India is approximately 9 MW. In India, approximately 190 large-scale biogas facilities with a cumulative capacity of 280 MW are currently operational. Additionally, approximately 90 compressed biogas/ biomethane facilities were established in India. The Sustainable Alternative towards Affordable Transportation (SATAT) scheme, which was initiated by

the Government of India, is designed to generate 15 million metric tons (MMT) of compressed biogas (CBG) from 5000 plants by 2023.

SOME BIOMASS-GASIFIERS PROJECTS IN INDIA

- Arashi Hi-Tech Bio-Power Private Limited (AHBPPL) has constructed a 1 MW biomass gasification power station in the Coimbatore district of Tamil Nadu. AHBPPL is India's first 1 MW grid-connected biomass gasification power facility. Coconut wastes, readily available in substantial amounts in this location, served as the primary fuel for this project activity. Biomass underwent gasification in two 500 kW gasifiers, and the resultant producer gas was directed to five 250 kW producer gas engines. The produced electricity was transmitted to the Tamil Nadu Electricity Board (TNEB) grid and utilized by its affiliated company through wheeling. AHBPPL commenced its power generation in January 2005, utilizing a 100% producer gas engine. The Combustion Gasification and Propulsion Laboratory (CGPL) branch of IISc served as the technology provider for this project.
- Chanderpur Renewable Power Company Pvt. Ltd. has implemented a 1 MW biomass gasifier at a factory located in Mullana, Ambala district, Haryana. This facility utilizes wood waste from plywood businesses, including tree branches and similar materials.
- Electricity supply to all three units of Chanderpur Group (CPG) via the grid. The generated power is directly synchronized with the grid and is being acquired by the group firms for their daily needs. It is the first project of its kind in North India. This plant not only meets all electrical requirements of CPG but also provides additional money to farmers via the sale of surplus biomass waste. In the initial phase, a 1000 kg/hr gasifier system was incorporated with four 250 kW Producer Gas Engines in 2012. The precise biomass consumption ranges from 1.2 to 1.5 kg/kWh.
- The Indian soya major, Ruchi Soya, has set up a 1 MW gasification plant in Washim, Maharashtra, as a Model Investment Project (MIP). It produces edible oil, and shall be using all the by-products from its crushing plant, which cannot be used as animal feed to convert into biofuel. The plant will be built by the Indian company, Thermax, using technology developed by the Energy Research Centre (ERC) and the Dutch company, Dahlman. The system has a conversion efficiency of more than 95% as opposed to a conversion efficiency of 80% to 85% of current technologies.
- Three biomass gasifiers (with a nominal capacity of 600 kg/hr biomass) have been installed at Mangaldoi, Assam, by GP Green Systems Pvt. Ltd. in Kolkata. The gas produced will have a calorific value of 1,250 - 1,350 kcal/Nm_3 (or 5.25 MJ–5.65 MJ/Nm_3). The purpose of this gas was to supplant the high-speed diesel (HSD) that was previously employed as a fuel in the biscuit plant of ITC. The customer's contentment was significantly enhanced by the venture's success. The facility has been in continuous operation since June 2016, when it was commissioned.
- Husk Power Systems, which was founded in 2007, was the first to employ rice husks for the purpose of generating electricity through biomass gasification. The company has developed over time to incorporate solar power and battery storage, resulting in hybrid mini-grids that provide rural

communities with renewable energy on a continuous basis. Husk has been operating more than 150 power plants since 2022, providing electricity to a multitude of villages in Africa and India.

- Ankur Scientific, a company located in Vadodara, Gujarat, is a specialist in the production of downdraft gasifiers with closed-top designs. Their products are designed to accommodate both thermal and electrical applications, with capacities ranging from 10 kW to 1,500 kW. They have created series such as WBG for wood fragments and coconut shells, FBG for fine biomass, such as rice husk, and the COMBO series for the processing of both fine and woody biomass.

Check Your Progress 6.3

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) What are the different applications of syngas?

.....

.....

2) Differentiate syngas and producer gas?

.....

.....

3) What is syngas?

.....

.....

4) Choose any one biomass gasifier project in India mentioned in the chapter and list:

- Feedstock used
- Capacity
- End use of produced gas or electricity

.....

.....

Activity 6.3

Visit a nearby place where a gasifier system is fixed and gather information pertaining to the installed capacity, fuel requirement for engines, running time and cost per KW production.

.....

.....

6.8 LET US SUM UP

As we know, Biomass Gasification is a chemical process that converts biomass into useful gaseous fuels or chemical feedstock. It is a promising technology to fulfil the energy requirement of the world and also significantly reduces the volume of biomass waste generated in developing countries. This conversion process has been used to meet the energy needs using different technological packages, right from domestic cooking to industrial heat and power production. During the thermo-chemical conversion process, the chemical structure of the biomass is changed by means of high temperature. With the help of gasification agents, the feedstock is quickly converted into gas by means of different heterogeneous reactions. The combustible gas contains Carbon Monoxide (CO), Hydrogen (H_2), Methane (CH_4), H_2O and Carbon dioxide (CO_2), trace amounts of higher hydrocarbons, inert gases and various contaminants such as small char particles, ash and tars.

The Ministry of New and Renewable Energy (MNRE) of the Government of India has been promoting productive and efficient utilisation of biomass for energy generation. Currently, most power production systems in India using biomass gasification are off-grid and have been for captive consumption for an industry or for a community. Rajasthan, Punjab, Maharashtra and Haryana are states having high biomass potential. As of September 2021, India's biomass-based power generation capacity was roughly 10.6 gigawatts (GW). This capability includes multiple technologies, such as direct combustion and cogeneration. Biomass gasification, a process that transforms biomass into syngas for energy production, represented around 140 megawatts (MW) of the overall capacity.

6.9 KEY WORDS

Anaerobic Digestion: The degradation and stabilization of organic materials brought about by the action of anaerobic bacteria with the production of biogas (bio-mechanization).

Animal Wastes: Animal wastes constitute the wastes from animal husbandry. Animal dung is a potentially large biomass resource.

Biofuel: A fuel that originates from biomass. Further, this fuel may have been altered chemically or biologically and originally had another use.

Biomass: Biomass is an organic matter comprizing a wide variety, including not only wood, crops, seaweed, animal wastes, marine plants, fisheries resources, but also pulp sludge, alcohol fermentation stillage, industrial waste, etc.

BTU: British thermal unit.

Combustion: Burning or incineration of a fuel using excess air or oxygen.

CHP: Combined Heat and Power. By taking advantage of the heat generated within the thermo-chemical process, a high total efficiency is achieved.

Feedstock: The material fed into a gasifier and converted into a synthesis gas (syngas).

Fossil fuel: Solid, liquid or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas and coal are fossil fuels.

FT (Fischer-Tropsch): The FT process was invented by Franz Fischer and Hans Tropsch in the 1920s. In this process, through catalytic reactions, the synthesis gas is converted to alkanes (paraffins) and alkenes (olefins).

Gasification: Gasification is a thermo-chemical process that converts carbon-containing materials, such as coal, petroleum coke (pet coke), biomass, waste, or other materials, with little or no oxygen present and at high temperatures, into a synthesis gas (syngas).

Gasifier: A vessel where the gasification reactions take place. In the gasifiers, the feedstock reacts with oxygen (or air) and water (or steam) at high temperatures.

Grid Connection: Joining a plant that generates electric power to a utility system so that electricity can flow in either direction between the utility system and the plant.

IGCC: Integrated gasification combined cycle.

Non-woody Biomass: Non-woody biomass is referred to as crop residues like straw, leaves and plant stems (agro wastes), processing residues like saw dust, bagasse, nutshells and husks, and domestic wastes (food, rubbish, sewage).

Oxidation: Chemical combination with oxygen.

Plasma: Often called the fourth state of matter (the other three are solid, liquid, and gas). Plasma is created when an electrical charge passes through a gas.

Producer Gas: The mixture of gases composed of carbon monoxide (CO) and hydrogen (H_2), plus carbon dioxide (CO_2) and typically a range of hydrocarbons such as methane (CH_4).

Pyrolysis: Thermo-Chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam.

Synthesis Gas (syngas): Syngas is an abbreviation for synthesis gas, which is a mixture comprising carbon monoxide, carbon dioxide, and hydrogen. The syngas is produced by gasification of a carbon-containing fuel (coal, municipal waste, etc) to a gaseous product that has some heating value.

Woody Biomass: All the biomass from forests, agro-industrial plantations, bush trees, urban trees and farm trees is termed as woody biomass.

6.10 SUGGESTED FURTHER READINGS/ REFERENCES

- Anil K. Rajvanshi, *"Biomass gasification"*, CRC Press, Maharashtra, India, Pages 83-102.
- Arthur McCarty James Rivas, 2012, *"The effect of biomass, Operating conditions and gasifier Design on the Performance of An Updraft Biomass Gasifier"*, Kansas State University, Kansas.
- Howes Pet, Warren Kathryn, *"Integration of thermal energy recovery into solid waste management"*, IEA Bio-energy annual report, Paris, 2013.
- IEA *Bio-energy– Biomass Gasification Status in India,* TASK 33, October 21, D. M Rao, R.M. Badhe, Research and Development Centre-IOCL Haryana.
- IEA *Bio-energy– Status report on thermal gasification of biomass and waste 2021,* TASK 33, February 22, Jitka Hrbek, University of Natural Resources and Life Sciences Vienna (BOKU), Austria.

- Overend Ralph P., 2004, "Thermo-chemical conversion of biomass: Renewable Energy Sources Charged with Energy from the Sun and Originated from Earth-Moon Interaction", *Encyclopedia of Life Support Systems (EOLSS)*, Oxford, UK.
- Pathak P.S., Khan T.A., Sharma P., *"Biomass production, its utilization and surplus for energy generation in India"*, Proceedings of the national seminar on biomass management for energy purpose– issues and strategies. SPRERI, VV Nagar, India, pp 10–35, 2004,
- Peter Mc Kendry, 2002, pages 47-54, *"Energy production from biomass (part 2): conversion technologies"*, Applied Environmental Research Centre Ltd, U.K.
- Ralph E.H. Sims, chapter 4, 2007, *energy supply,* Cambridge University Press, Cambridge.
- Richard L. Bain, 2004, *"An Introduction to Biomass Thermo-chemical Conversion"*, DOE/NASLUGC Biomass and Solar Energy Workshops, Battelle.
- Srinivas, S.N., Ravindranatha, N.H., Shrinivasa, U., Dasappa, S., and Mukunda, H.S. 1991, *"A gasifier-based rural power generation system: Performance and problems",* Proc. Third National Conference on Biomass, Baroda.
- http://www.seco.cpa.state.tx.us/publications/renewenergy/biomassenergy.php

6.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 6.1

1) (a) Physico-chemical conversion

   (b) Biochemical conversion

   (c) Thermo-chemical conversion

2) To avoid the trapping of gas, a gasifier plant must be installed in the open air or well-ventilated areas.

3). Anaerobic digestion (AD) is the process whereby bacteria break down organic material in the absence of air, yielding a biogas containing methane. It is also the natural process that can break down organic material in pools and marshes to produce marsh gas and in landfills to produce landfill gas.

4) Two main limitations in thermal conversions are moisture content and ash. Fuel wood is the most commonly used fuel in rural parts of India.

Check Your Progress 6.2

1) A biomass gasifiers are those devices that convert biomass (wood blocks, wood chips, rice husk, sawdust, and other such agricultural residues) into a combustible gas called "producer gas". The producer gas has a lower calorific value than CNG/LPG, but still can be used in ovens/furnaces where the temperature requirement is less than 900 °C.

2) The gasifier is a thermal reactor that thermally cracks the biomass into a gaseous state by the application of intense heat in a controlled oxygen-starved atmosphere. The biomass is fed at the top of the reactor and moves downwards towards the grate by gravity. During this motion, it passes through the "drying", "pyrolysis", "controlled combustion" and "reduction" zones in that order. The boundary of each of the above zones is not rigid but transitional. Moreover, depending on the wood characteristics and the load, the height of each zone also varies. Each of the zones has a specific reaction component to perform, resulting in the formation of "producer gas" and ash/char mixture at the end of the reduction zone.

Component	Percentage Value
Carbon monoxide	18-22 %
Hydrogen	13-19 %
Methane	1-5 %
Heavier hydrocarbons	0.2-0.4 %
Carbon dioxide	9-12 %
Nitrogen	45-55 %
Water vapour	4 %

Check Your Progress 6.3

1) Syngas is used as an intermediate in the industrial synthesis of hydrogen and ammonia. It can be burnt and is used as a fuel source. It is used as a fuel in power generation using an IGCC power plant.

2) The syngas is composed of 85% carbon monoxide and hydrogen, and small amounts of methane and carbon dioxide. If the gasification product also contains a significant amount of non-combustible gases such as nitrogen and carbon dioxide, the term used for such mixtures is 'Producer Gas.

3) Syngas is an abbreviation for synthesis gas, which is a mixture comprising carbon monoxide, carbon dioxide, and hydrogen. The syngas is produced by gasification of a carbon-containing fuel (coal, municipal waste, etc.) to a gaseous product that has some heating value. The resultant syngas is composed of 85% carbon monoxide and hydrogen, and small amounts of methane and carbon dioxide.

4) Selected Biomass Gasifier Project: Arashi Hi-Tech Bio-Power Private Limited (AHBPPL), Tamil Nadu

- **Feedstock Used:**

  Coconut waste

- **Capacity:**

  1 MW (Two 500 kW biomass gasifiers coupled with producer gas engines)

- **End use of Produced Gas or Electricity:**

  The producer gas is used in gas engines to generate electricity, which is supplied to the Tamil Nadu Electricity Board (TNEB) grid and utilized by the associated industry through power wheeling.

UNIT 7 GASIFICATION SYSTEMS AND APPLICATIONS

Structure

7.0 Objective

7.1 Introduction

7.2 Theory of Gasification

7.3 Types of Gasifiers

7.4 Process Zones in the Gasifiers

7.5 Operating Parameters

7.6 Case Study on Gasification

7.7 Cooling and Cleaning of Gas

- 7.7.1 Gas Cooling
- 7.7.2 Gas Cleaning
- 7.7.3 Cooling and Cleaning System

7.8 Performance Characteristics

7.9 Let Us Sum Up

7.10 Key Words

7.11 Suggested Further Reading/References

7.12 Answers to Check Your Progress

7.0 OBJECTIVES

After reading this Unit, you will be able to:

- define the basic concepts related to gasification and explain the fundamental theory and principles of gasification;
- illustrate the types of gasifiers and their working mechanisms;
- differentiate between various gasification technologies and identify the influence of operating parameters on system performance;
- discuss the efficiency and performance characteristics of different gasifiers based on real-life case studies; and
- discuss on the precautions to be taken for the maintenance of the gasification process.

7.1 INTRODUCTION

Gasification is a technology that dates back more than a hundred years and gained prominence during the Second World War when it served as a substitute for petroleum-based fuels. Once liquid fuels became readily available, the use of gasification declined rapidly. However, in the later part of the 20th century,

renewed attention was drawn to this technology due to its potential to convert solid biomass into clean, energy-rich gases. Today, with the rising cost of fossil fuels, depleting natural resources, and growing global environmental concerns, gasification has re-emerged as a modern, efficient, and sustainable energy generation technology. For our Agribusiness Management learners, understanding gasification holds significant importance. Agriculture produces a large volume of residues such as crop stalks, husks, shells, and other organic wastes that often remain underutilized. Gasification offers an innovative way to transform these agricultural residues into valuable energy sources like syngas, bio-oil, or biochar. This not only contributes to clean energy generation but also provides a pathway to circular economy models where waste is converted into wealth. From an agribusiness perspective, knowledge of gasification enables students to explore sustainable business ventures in renewable energy. Establishing a small or medium-scale biomass gasification unit can be a profitable enterprise, especially in rural or semi-urban areas where agricultural residues are abundant. Such ventures can power local agro-processing industries, cold storage units, and farm machinery, thereby reducing dependency on expensive fossil fuels. However, today with increasing prices of fossil fuel and increazing environmental concern, this technology has become the topic of interest and has been developed as a more modern and sophisticated technology will be discussed in this Unit.

7.2 THEORY OF GASIFICATION

Let's first understand the science behind gasification. Just like combustion, gasification is a thermal conversion process. In this, both heat and combustible product gases are generated. Similar to combustion, one of the methods in gasification is referred to as "partial oxidation". It is different from combustion because of the requirement of an insufficient oxygen supply for complete combustion to occur. In a second method with steam as the oxidising agent, the biomass is heated directly without oxygen or air. It involves partial combustion of biomass at temperatures of about 1000 °C. The reactor is called a "*gasifier*", as shown in Fig. 7.1.

The product gas can be a medium-energy content gas called as "syngas" or "synthetic gas" or a low-energy content gas often called as "producer gas". Syngas contains mainly carbon monoxide and hydrogen. Higher-quality syngas can be produced by using pure oxygen as the oxidising agent or by indirect heating. Producer gas results if air is used as the oxidising agent, which dilutes the combustible components of the gas with nitrogen, as shown in Fig. 7.1. Generally, producer gas is adequate for power generation. It helps to avoid the energy use associated with oxygen production. Syngas is required for chemical production.

However, in gasification, where there is an excess of production of solid fuel (incomplete combustion), the products of combustion contain (Fig. 7.1) combustible gases like Carbon monoxide (CO), Hydrogen (H_2) and residues of Methane and waste products like tar and dust. Through the glowing layer of charcoal, these gases are produced by the reaction of carbon dioxide (CO_2) and water vapour (H_2O). Thus, the idea to design a gasifier is to develop conditions so that a) biomass is reduced to charcoal and b) charcoal is converted to produce carbon monoxide and hydrogen at a suitable temperature.

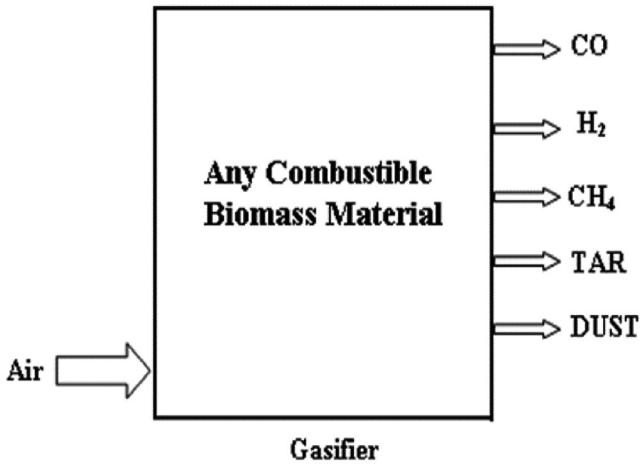

Fig. 7.1: Products of Gasification

7.3 TYPES OF GASIFIERS

Basically, gasifiers are classified into five major types: fixed-bed updraft, fixed-bed downdraft, fixed-bed crossdraft, bubbling fluidised bed, and circulating fluidised bed gasifiers. The differences in different types of gasifiers are based upon: (i) the direction of flow of both the biomass and oxidant, (ii) supporting the biomass in the reactor vessel and (iii) the way heat is supplied to the reactor.

Now We Discuss Different Types of Gasifiers in Detail:

i) **Fixed-bed Gasifier:** Fixed-bed systems are simple and cost-effective, ideal for small-scale energy needs, while fluidised-bed gasifiers are more advanced and suitable for large-scale, multi-fuel operations. Fixed-bed gasifiers can be classified primarily as updraft, downdraft and cross-draft (shown in Fig. 7.2).

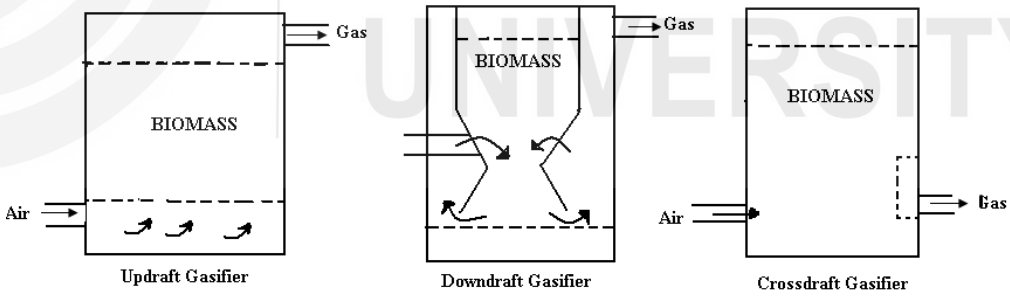

Fig. 7.2: Various Types of Gasifiers

ii) **Fixed-bed Updraft Gasifier:** Updraft gasifiers represent the oldest and simplest gasifiers. A schematic of the updraft gasifier is shown in Fig. 7.3, where biomass is introduced from the top, and air or steam enters from the bottom. The gases move upward through the descending biomass, leading to high thermal efficiency but also higher tar content in the producer gas. It operates at a combustion zone temperature of about 1200°C, producing gas that exits at around 500°C. Its advantages include simplicity, fuel flexibility, and high equipment efficiency, but challenges such as tar formation and channelling limit its applications to direct heating and steam generation systems. For this reason, updraft gasifiers are usually operated in a close-coupled mode to a furnace or boiler to produce steam or hot water.

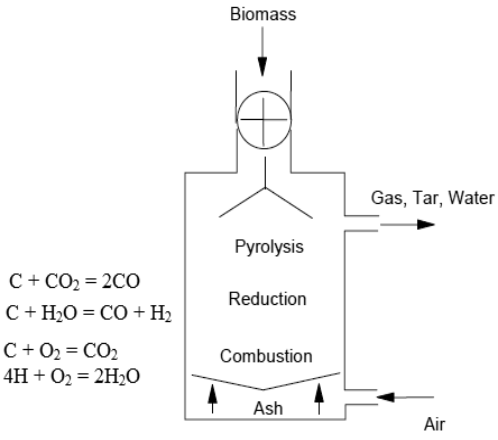

Fig. 7.3: Updraft Gasifier

iii) Fixed-bed Downdraft Gasifier: In the downdraft gasifier, both biomass and air flow downward in the same direction. This co-current movement reduces tar formation as gases pass through the high-temperature combustion zone (800-1200°C). The gas produced exits at around 700°C and is relatively clean, making it suitable for small engines and power generation. Downdraft systems are environmentally friendly and produce low-tar gas but require uniform, low-moisture biomass with less than 20% moisture content. Their limitations include lower efficiency and difficulty handling low-density or unprocessed fuels, as schematically shown in Fig. 7.4.

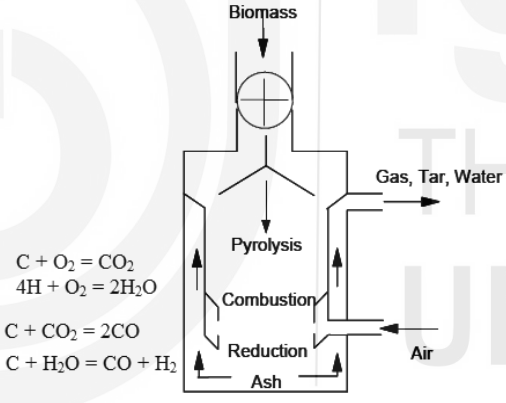

Fig. 7.4: Downdraft Gasifier

iv) Cross-draft Gasifiers: The cross-draft gasifier, a variation of the downdraft system, introduces air tangentially at the bottom, allowing gases to move horizontally across the reactor. It typically uses high-quality charcoal as feedstock and operates at very high temperatures (up to 1500°C). This design is suitable for very small-scale power generation units (below 10 kW) due to its simple operation and compact size. However, it requires premium-grade fuel with low volatile content, which limits its flexibility. Despite this, its low cost and simple gas-cleaning system make it ideal for decentralized rural energy solutions.

v) Bubbling Fluid Bed: he bubbling fluidised-bed gasifier employs an inert medium such as sand or alumina, which is fluidised by air or steam. Biomass is introduced at the bottom, and uniform temperature distribution (around 700 - 900°C) ensures efficient gasification with high conversion rates (95 - 99%) and low tar formation. Catalysts can be added to enhance performance and reduce impurities. The BFB system is fuel-flexible and

suitable for medium-scale projects (up to 25 MWth), handling diverse materials such as wood waste, straw, and agro-residues. However, it requires careful moisture control and a complex air-blower system.

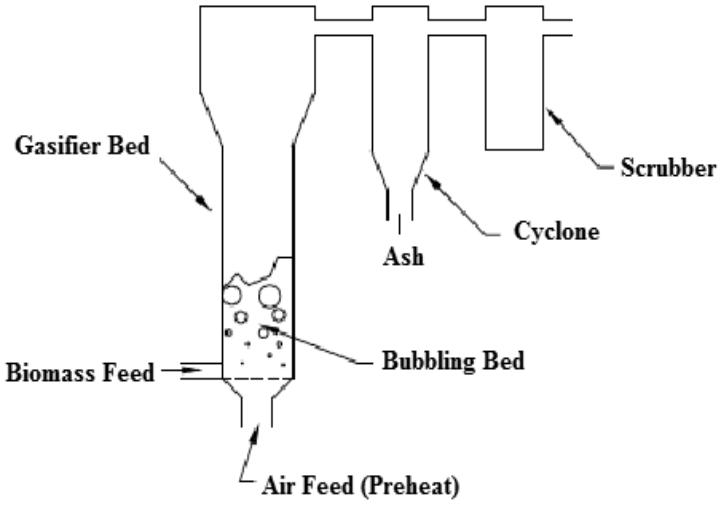

Fig. 7.5: Bubbling Fluid Bed Gasifier

vi) **Circulating Fluid Bed:** The circulating fluidised-bed gasifier operates at higher gas flow rates, which carry solid particles and unconverted biomass into a cyclone separator. These solids are then recirculated to the reactor, forming a continuous loop that improves heat transfer and reaction efficiency. CFB gasifiers provide excellent scalability, supporting capacities from a few MWth to large commercial units. Their design allows for uniform gas-solid mixing, efficient carbon conversion, and flexibility in feedstock use. Though more complex and costly to construct, they are highly suitable for industrial-scale biomass power and combined heat and power (CHP) applications, as shown in the Fig. 7.7. The main difference between the circulating fluid bed and bubbling fluid is that in the circulating fluid bed there is no separation between the dilute solids zone and dense solids zone.

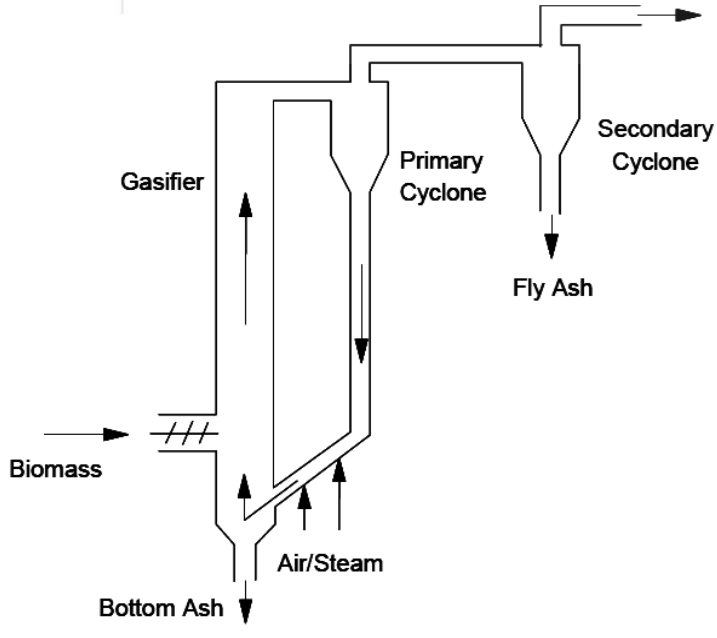

Fig. 7.6: Circulating Fluid Bed Gasifier

Summary of Different Types of Gasifiers

A detailed summary of different types of gasifiers is explained in Table 7.1

Table 7.1 : Detailed Summary of Different Types of Gasifiers

Gasifier Type	Scale	Typical Temperatures		Fuel Requirements		Efficiency	Gas Characteristics	Other Notes
		Reaction	Operating	Moisture Content (%)	Flexibility			
Downdraft Fixed Bed	5 kW_{th} to 2 MW_{th}	1000°C (1800°F)	800°C (1450°F)	<20%	• Less tolerant of fuel switching • Requires uniform particle size • Large particles	Very good	•Very low tar •Moderate particulates	• Small Scale • Easy to control • Produces biochar at low temperatures. • Low throughput. • Higher maintenance costs
Updraft Fixed Bed	<10 MW_{th}	1000°C (1800°F)	250°C (480°F)	up to 50%-55%	• More tolerant of fuel switching than downdraft	Excellent	•Very high tar (10% to 20%) •Low particulates •High methane	• Small- and Medium-Scale • Easy to control • Can handle high moisture content • Low throughput
Bubbling Fluidized Bed	<25 MW_{th}	850°C (1550°F)	800°C (1450°F)	<5 to 10%	• Very fuel flexible • Can tolerate high ash feedstocks • Requires small particle size	Good	• Moderate tar • Very high in particulates	• Medium Scale • Higher throughput • Reduced char • Ash does not melt • Simpler than circulating bed
Circulating Fluidized Bed	A few MW_{th} up to 100 MW_{th}	850°C (1550°F)	850°C (1550°F)	<5 to 10%	• Very fuel flexible • Can tolerates high ash feedstocks • Requires small particle size	Very Good	•Low tar •Very high in particulates	• Medium to Large Scale • Higher throughput • Reduced char • Ash does not melt • Excellent fuel flexibility • Smaller size than bubbling fluidized bed

Check Your Progress 7.1

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) Explain the reaction zone and pyrolysis zone processes in the fixed-bed gasifier.

.....

.....

2) What are the aims and advantages of biomass gasification?

.....

.....

3) What is the use of Cyclones in the bubbling-bed and circulating-bed gasifiers?

.....

.....

Suggestions for Thought and Discussion On Agribusiness Management

MBA (Agribusiness Management) students can explore several ventures:

- **Energy-based Enterprises:** Setting up gasifier plants for rural electrification or agro-processing units.
- **Consultancy and Training:** Offering project design, feasibility analysis, and technology advisory.
- **Value Addition:** Marketing biochar or ash residue as soil conditioners or organic fertilizers.
- **Green Startups:** Partnering with farmer cooperatives or FPOs for decentralized bioenergy generation and many more opportunities.

7.4 PROCESS ZONES IN THE GASIFIERS

Different zones like drying, pyrolysis, reduction and combustion (oxidation) develop along the reactor in the gasifiers, as air is passed through the fuel bed. The position of these zones in the gasifier depends on the relative movement of the fuel and air. These zones are differentiated by their various chemical reactions occurring inside the bed and the temperature regimes at that point. The depth and relative importance of each zone depend on the chemical composition of the feedstock, its moisture content and particle size, the mass flow rate of the gasifying agent, and the temperature.

a) **Drying of fuel :** The rate of drying (reduction of moisture) depends mainly on the temperature, velocity, and moisture content of the drying gas. As the fuels move inside the drying zone, their internal temperature is increazed to 100-150^{o}C. No chemical reactions take place in this zone.

b) **Pyrolysis :** Pyrolysis turn waste into an energy-rich fuel by heating the waste under controlled conditions. In this process, tar and other volatiles are driven off,

c) **Combustion :** In the combustion zone, the outputs from the above zone react with the remaining char in the absence of oxygen at a temperature of around 800-900 °C. Equations 1 and 2 indicate the basic reactions of combustion.

Basic Reactions:

$$C + O_2 \longrightarrow CO_2 \qquad (1)$$

$$4\,H + O_2 \longrightarrow 2\,H_2O \qquad (2)$$

$$C_nH_m + (n/2+m/4)\,O_2 \longrightarrow n\,CO_2 + m/4\,H_2O$$

d) **Reduction :** In this region, the hot gases formed in the above process are converted into "Producer Gas" by the following (Eq. 3 and 4) two endothermic reactions.

Boudouard reaction: $C + CO_2 \longrightarrow 2CO$ HR = + 160.9 kJ/mol (3)

Water gas reaction: $C + H_2O \longrightarrow H_2 + CO$ HR = + 118.4 kJ/mol (4)

Fig. 7.7 shows an updraft gasifier with different zones and their respective temperatures schematically. Fig. 7.8 and 7.9 show these regions for downdraft and cross draft gasifiers, respectively.

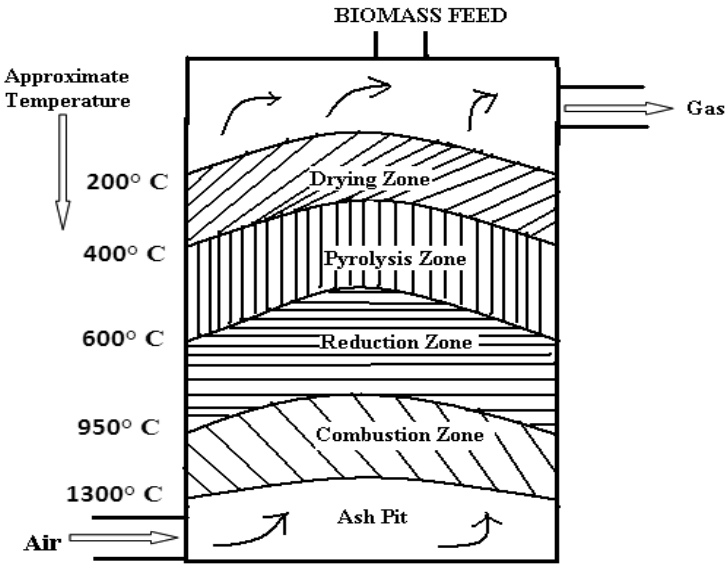

Fig. 7.7: Various Zones in the Updraft Gasifier

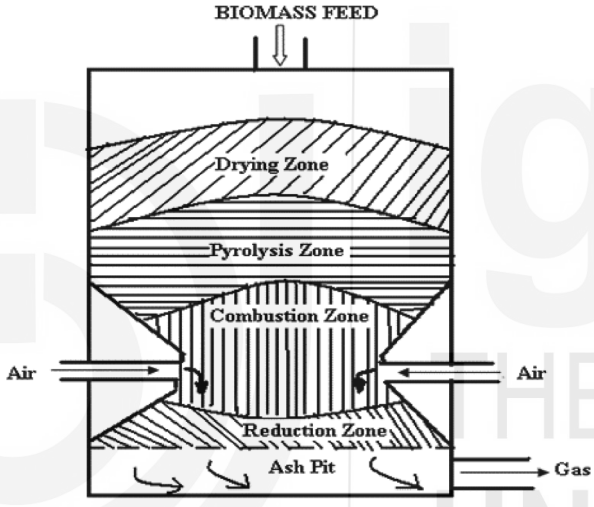

Fig. 7.8: Various Zones in the Downdraft Gasifier

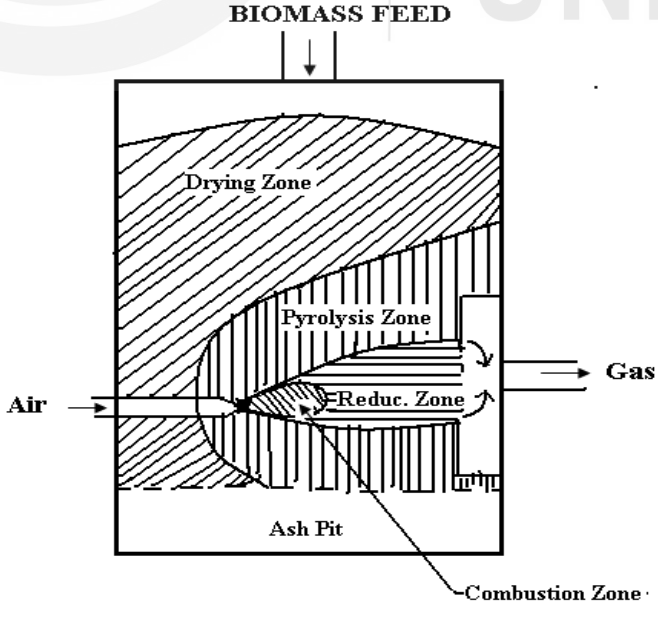

Fig. 7.9: Gasification Process in Crossdraft Gasifier

7.5 OPERATING PARAMETERS

The performance and quality of producer gas in a gasifier depend on several operating and feedstock parameters. The major influencing factors are discussed below:

i) Operating Temperature

Temperature strongly affects gas yield and composition. Higher temperature (>800°C) improves carbon conversion, increases H_2 and CO content, and reduces tar formation. At >850°C, Boudouard and steam reforming reactions dominate, enhancing gas quality.

ii) Equivalence Ratio (ER)

ER is the ratio of actual air supply to the air needed for complete combustion. Moderate ER values improve producer gas yield, calorific value, and gas efficiency. The excess air can lead to more CO_2 and lower heating value.

iii) Moisture Content

- Biomass should have <20% moisture for efficient gasification.
- High moisture causes heat loss and lowers gas quality.
- Updraft gasifiers tolerate higher moisture (up to 40%), but downdraft types perform best with dry fuel.

iv) Dust Content

- All gasifiers generate some dust, which can clog engines if not filtered.
- Acceptable dust level: 2–6 g/m³.
- Proper filtration systems are essential for smooth operation.

v) Tar Content

- Tar can block carburettors and valves, causing maintenance issues. And its formation depends on temperature and heat rate.
- Downdraft gasifiers typically produce less tar compared to other types.

vi) Ash and Slagging Characteristics

- Ash is the incombustible residue left after fuel burning. The problems arise when ash fuses into slag, obstructing fuel flow or covering ignition points, reducing reactivity.
- Regular cleaning and using low-ash fuels prevent such issues.

vii) Superficial Velocity (SV)

- SV represents the gas flow rate relative to the reactor cross-section.
- Low SV → slow pyrolysis, more char and tar.
- High SV → faster reactions but less residence time, reducing tar cracking efficiency.

viii) Gasifying Agents

- The type of oxidising agent (air, steam, oxygen, CO_2) determines syngas quality.
- Air gasification produces low-calorific gas (due to N_2 dilution).
- Steam or steam–oxygen mixtures yield higher H_2 content and medium-calorific gas.

ix) Residence Time

- Longer residence time promotes tar cracking but can reduce gasification efficiency.
- Optimising residence time ensures balanced gas composition and better conversion.

7.6 CASE STUDY ON GASIFICATION

- **Biomass and biogas enterprises are turning agricultural waste into sustainable energy:**

  Biomass refers to all organic materials derived from plants, animals, and their residues that can be used to produce energy. In agriculture, it includes crop residues such as rice straw, wheat husk, and sugarcane bagasse, as well as animal manure, poultry litter, and waste from agro-industrial processing like fruit peels or oil cakes. These materials, often considered as waste, are valuable renewable resources that can be transformed into bioenergy through scientific treatment methods. Using agricultural waste for energy production aligns with the principles of a circular economy and sustainable agribusiness, where waste becomes a valuable input instead of a disposal problem. It also helps reduce pollution, particularly from practices such as crop residue burning, and supports rural energy self-sufficiency.

- **Treatment and Conversion of Biomass into Energy:**

  The conversion of biomass into useful energy involves different treatment methods: biological, physical, and chemical. Physical pretreatment includes chopping, shredding, and milling to increase surface area for microbial action. Chemical pretreatment involves the use of acids or alkalis to break down lignin and cellulose in hard residues like straw or bagasse. Biological pretreatment employs microbes or enzymes to decompose complex organic materials. Among these, anaerobic digestion is the most suitable and cost-effective method for agricultural applications, as it converts organic waste into biogas under oxygen-free conditions. Biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), and can be used for electricity generation, heating, or as an upgraded biomethane fuel. The residue left after digestion, called digestate, is rich in nutrients and can be used as a natural fertilizer.

- **The Process of Biogas Production:**

  Anaerobic digestion takes place in a digester, a closed tank where organic material is decomposed by microorganisms in the absence of oxygen. The process involves stages such as hydrolysis, acidogenesis, acetogenesis,

and methanogenesis, which ultimately produce biogas and digestate. Feedstocks such as cattle dung, poultry waste, vegetable waste, and crop residues are commonly used. The efficiency of biogas production depends on factors like feedstock type, organic loading rate, retention time, and temperature. *For example*, a mesophilic digester operates at around 35-40°C, while thermophilic systems function at higher temperatures (50-55°C) and offer faster digestion but higher energy input. The digestate obtained can be separated into solid and liquid forms for composting or direct application to fields, enhancing soil fertility.

- **Steps for Setting Up a Biogas Plant:**

  For a student or entrepreneur in agribusiness management, starting a biogas plant involves several structured steps. The first step is to assess the availability and type of feedstock, whether it is manure, crop residues, or agro-industrial waste and determine its quantity, seasonality, and chemical composition. The second step is to choose an appropriate technology and scale. The design of the digester, size of the plant, and type of reactor (batch or continuous) depend on feedstock characteristics and expected gas yield. The next stage involves mass and energy balance calculations, which help estimate the amount of methane generated and energy output. This can be done using standard biogas yield coefficients available in literature or tools like the "Investment Decision Tool" developed by Karellas *et. al*.

  Once the technical parameters are established, an economic feasibility study must be undertaken. This includes estimating the capital cost (CAPEX) for plant construction and equipment, and operating costs (OPEX) for labour, feedstock handling, maintenance, and utilities. Potential revenue sources include the sale of electricity or biomethane, the use or sale of digestate as organic fertiliser, and even carbon credits. The next steps involve securing finance, obtaining regulatory clearances, constructing the plant, and ensuring efficient operations and monitoring. Continuous evaluation of biogas yield, energy output, and financial performance is essential for long-term success.

- **Economic Aspects of Biogas Production:**

  The economic viability of a biogas plant depends on several factors, such as feedstock cost and availability, plant size, technology choice, and energy pricing. The total project cost includes the digester, gas collection and upgrading units, and infrastructure like feedstock storage and pipelines. Operating costs include labour, transportation of feedstock, maintenance, and insurance. Revenues are generated through energy sales, fertilizer substitution, and waste disposal savings. Financial analysis using parameters like Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period helps in evaluating project feasibility.

  Studies show that small-scale biogas plants often face challenges in achieving profitability without government incentives. Subsidies or grants that cover 40 - 60% of the capital cost significantly improve viability. Economies of scale are critical; larger plants spread fixed costs more effectively. In India, where feedstock is abundant but often scattered, cooperative or cluster-based biogas plants, where multiple farms pool their residues and manure, are found to be more sustainable. Additionally,

using digestate as a bio-fertilizer can reduce chemical fertilizer expenses, improving both economic and environmental outcomes.

For example, a medium-sized biogas plant using around 10,000 tonnes of agricultural residue and manure annually can produce approximately 600,000 cubic meters of biogas per year. If converted to electricity, this would generate about 3.3 million kWh annually. However, without scale and efficient utilization of by-products, such projects may not yield attractive financial returns, underscoring the need for careful planning and diversification of revenue sources.

- **Risks, Challenges, and Enabling Factors:**

  Biogas projects, while promising, face certain challenges. The most critical is the variability and seasonality of feedstock supply, especially when residues are only available after harvest seasons. Transport and logistics costs can also be high in rural areas. Technological risks include lower-than-expected gas yields, operational downtime, and maintenance issues. Market risks involve changes in energy tariffs or digestate demand, while regulatory risks arise from changing environmental norms or delays in obtaining permits.

  To overcome these, several enabling factors are necessary: reliable feedstock supply chains, suitable plant design, skilled technical personnel, and supportive policies. Integration with existing agribusiness operations, such as dairy farms or sugar mills, enhances both efficiency and profitability. The social acceptance and environmental compliance (such as odour and emission control) play important roles in project success. The involvement of local communities and cooperatives can also create shared ownership and ensure steady feedstock flow. The biogas and biomass energy systems are essential tools for sustainable agribusiness. They convert agricultural waste into valuable energy, reduce farm costs, and promote environmental responsibility. For MBA students, the study of biogas plant development combines technical understanding with managerial, financial, and strategic skills. The key learning is that success depends on efficient resource utilisation, economic viability, and integration within the broader agribusiness ecosystem. Students who understand the interlinkages between agricultural production, waste management, and renewable energy will be well-positioned to lead future innovations in the agribusiness sector.

7.7 COOLING AND CLEANING OF GAS

Before going to the gas engine, the gas needs to be cooled and cleaned. Withdrawn from the gasifier at approximately 850 °C, it is cooled down to about 150°C in the subsequent product gas cooler as shown in Fig. 7.10. The heat obtained is used for different applications. As the producer gas is further cooled to provide an optimal inlet temperature for the gas engine, water and tars are condensed. Because of this special procedure, virtually all residues in the process can be recycled.

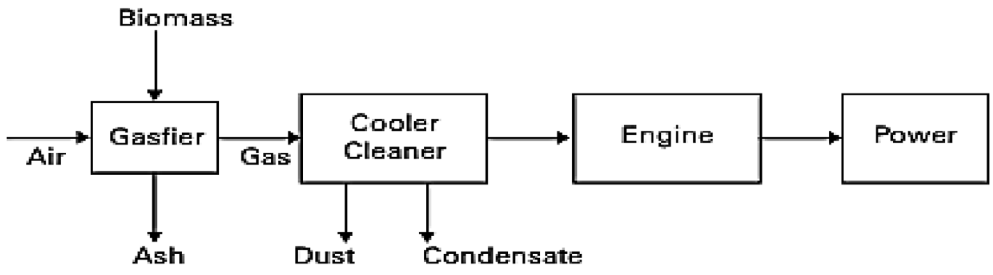

Fig. 7.10: Gasifier System for Power Generation

Trouble-free operation of an internal combustion engine using producer gas, clean gas is fairly required. As we know that well well-designed downdraft gasifiers are able to meet the criteria for cleanliness at least over a fairly wide capacity range (*i.e.* from 20% - 100% of full load). Updraft gasifiers in engine applications have to be fitted with bulky and expensive tar-separating equipment. If suitable fuels are used, the gasifier and cleaner are well designed, and the gasifier is operated above minimum capacity, then tar contamination of the gas does not present a major problem.

7.7.1 Gas Cooling

Gas cooling is carried out to **increaze gas density** and **improve engine efficiency**. A 10% reduction in gas temperature can increaze engine output by about 2%. Cooling also helps **remove moisture** and **impurities,** preventing condensation and improving combustion.

Types of Gas Coolers:

1. **Natural Convection Coolers –** Simple pipes; easy to use, no energy input, but bulky.
2. **Forced Convection Coolers –** Use a fan for air circulation; compact but require extra energy.
3. **Water Coolers/Scrubbers –** Use water spray or heat exchangers to cool and clean gas simultaneously; effective but need regular water and maintenance.

7.7.2 Gas Cleaning

Gas cleaning removes dust, tar, and impurities like ammonia, H_2S, and alkalis to make gas suitable for engines or chemical conversion. The effectiveness of a gasifier largely depends on its ability to produce clean, cool gas.

Common Cleaning Devices:

- **Cyclones:** Remove coarse dust before cooling.
- **Hot Gas Filters / Bag Filters:** Trap fine dust particles.
- **Scrubbers:** Use water or oil sprays for dust and tar removal.
- **Sand Bed or Activated Carbon Filters:** For fine purification.

Specific Impurity Removals:

- **Particulates:** Removed by cyclones, ESPs, or wet scrubbers.
- **Alkalis:** Removed through cooling and barrier filters.

- **Nitrogen Compounds:** Ammonia is removed via wet scrubbing or catalytic decomposition.
- **Sulfur Compounds:** H_2S and SO_2 are removed by using limestone or dolomite.
- **Tar:** Controlled by optimising gasifier design (primary) or catalytic/ thermal cracking (secondary).

7.7.3 Cooling and Cleaning System

The gas from the generator (300–500°C) must be cooled to near ambient temperature before use. Cooling enhances energy density and protects engines.

Integrated Cooling and Cleaning Process:

1. **Cyclone Filter:** Removes large dust (>5 μm).
2. **Wet Scrubber:** Cools and removes tar and fine dust through water washing.
3. **Cloth/Cork Filter:** Final dry-cleaning stage before gas enters the engine.

Properly designed cooling and cleaning systems ensure efficient, clean, and sustainable operation of biomass gasifiers.

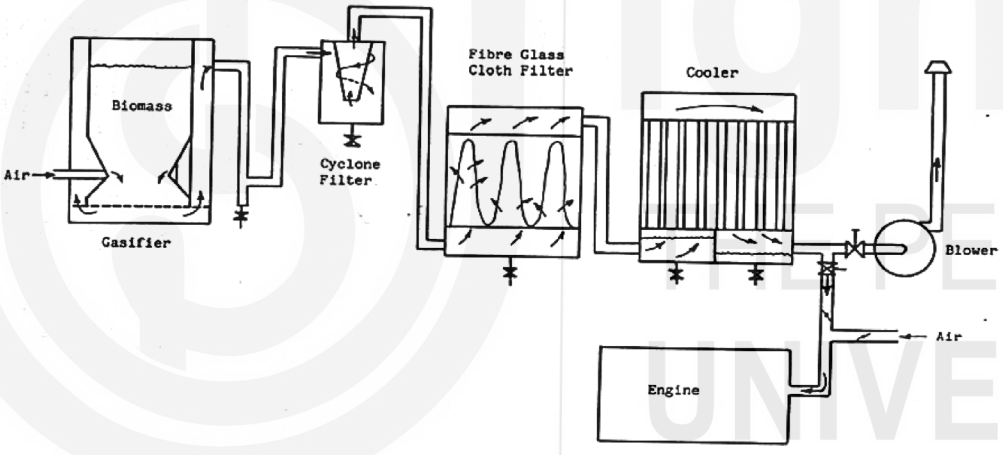

Fig. 7.11: Schematic Block Diagram of the Producer Gas Plant with Cleaning and Cooling

Check Your Progress 7.2

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) List the various zones of the gasifier systems. In which zone are tar and other volatiles driven off?

.....

.....

2) Why do we require low-moisture-containing fuels for gasifiers? What are the disadvantages of high-moisture-containing fuel?

.....

.....

3) Arrange the following components in the correct order for gas cooling and cleaning:

- Wet scrubber
- Gas engine
- Cyclone separator
- Cloth filter

.....

.....

4) List **two advantages** and **one limitation** of water scrubbers used in gas cleaning.

.....

.....

Activity 7.1

Visit a nearby place where a gasifier system is fixed and gather information about the cleaning and cooling equipment. Also, collect information about the utilisation of various residues of the producer gas.

.....

.....

7.8 PERFORMANCE CHARACTERISTICS

Biomass gasification systems convert biomass feedstocks into synthesis gas (syngas), a composition of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4), either for energy generation or as a feedstock for chemical manufacturing. The performance attributes of these systems depend upon the biomass type, gasifier configuration, and operational parameters. The following are the major performance attributes:

1. Conversion Efficacy

- **Cold Gas Efficiency (CGE):** Generally, 60-75%, indicating the efficacy of transforming biomass into syngas energy.
- **Thermal Efficiency:** Relies on heat recovery systems; with improved designs, it can attain 70-85%.
- **Carbon Conversion Efficiency:** The ratio of carbon in biomass transformed into gaseous products, frequently surpassing 90%.

2. Characteristics of Feedstock

- **Categories of Biomass:** Comprises wood chips, agricultural byproducts, forestry waste, and energy crops.
- **Moisture Content:** Significantly impacts performance; feed-stocks with less than 20% moisture are ideal. Excessive moisture diminishes efficiency by causing energy losses throughout the drying process.
- High ash content can result in slagging, fouling, and diminished gasifier efficiency.

3. **Syngas Quality**

- **Composition:** Syngas generally comprizes 15-20% H_2, 15-20% CO, 10-15% CO_2, along with trace amounts of CH_4 and other hydrocarbons.
- **Calorific Value:** Inferior to fossil-fuel-based gasification, approximately 4-7 MJ/Nm^3, depending upon the gasification medium.
- **Impurities:** Comprizes tar, particles, and alkali metals, requiring efficient cleaning systems.

4. **Gasifier Operational Parameters**

- **Temperature:** Biomass gasifiers function within a range of 700°C to 1,200°C.
- **Pressure:** While most systems function at atmospheric pressure, pressurized systems enhance syngas quality.
- **Gasification Agent:** Utilization of air, oxygen, or steam occurs. Air causes nitrogen dilution, resulting in inferior syngas quality, whereas oxygen and steam yield superior syngas quality.

5. **Environmental Performance**

- **Carbon Neutrality:** Biomass is deemed carbon-neutral when sourced sustainably, as the CO_2 emitted during combustion is equivalent to the CO_2 absorbed during its growth.
- **Emission Control:** Efficient technologies for tar and particle removal reduce pollution.
- **Waste Reduction:** Biomass gasification transforms waste into energy, hence diminishing landfill utilization and environmental repercussions.

6. **Management of Tar and Particulates**

- **Tar Formation:** A critical challenge in biomass gasification, particularly at reduced operating temperatures. Advanced designs and additional cracking techniques are necessary to reduce tar content.
- **Particulate Elimination:** Cyclones, filters, and scrubbers are commonly employed to purify the syngas.

7. **Scalability**

- **Small-Scale Systems:** Typically utilized for localized energy generation in rural or off-grid regions.
- **Large-Scale Systems:** Developing for industrial applications, integrated with combined heat and power (CHP) or biorefineries.

8. **Economic Viability**

- **Capital Costs:** Inferior to those of fossil-fuel-based systems, although depending upon the gasifier technology employed (fixed-bed, fluidised-bed, entrained flow).
- **Operational Expenses:** Affected by feedstock processing, maintenance, and syngas purification needs.

- **Revenue Streams:** Syngas can be utilised for electricity generation, biofuel production, hydrogen synthesis, or chemical manufacturing, hence improving economic viability.

9. **Flexibility of Processes**
   - **Various Outputs:** Generates syngas for energy, biofuels, or chemicals. Ash by-products may serve as fertilizer.
   - **Integration Potential:** Capable of being incorporated with renewable energy sources or industrial operations to improve sustainability.
10. **Limitations**
   - **Feedstock Supply Chain:** The availability of biomass and associated logistics may constrain scalability.
   - **Tar and Ash Management:** Necessitates robust structures for handling contaminants.
   - **Lower Energy Density:** Biomass-derived syngas possesses a lower calorific value compared to syngas obtained from coal or natural gas.

Biomass gasification is an advantageous method for sustainable energy generation, providing adaptability, diminished emissions, and carbon-neutral functionality when combined with sustainable biomass procurement. Advancements in gasifier design, tar management, and cost reduction are essential for enhancing its competitiveness.

The selection criteria of the biomass gasifier system depend mainly on the following points;

i) Type of gasifier feedstock: natural biomass or (biomass) waste;

ii) Types of gasifier design (downdraft/updraft/crossdraft, etc.);

iii) Gas engine type (*e.g. c*ompression ignition, spark ignition);

iv) Quality of the gas, *i.e.* end-product quality.

v) Application of the fuel, *i.e.* direct heating application, for electricity generation, irrigation, etc.

Precautions and Maintenance

Safe operation and regular maintenance are vital for efficient gasification.

1. **Safety During Operation**
   - Never open the gasifier when hot.
   - Use gloves, masks, and safety gear.
   - Allow cooling for at least 10 - 12 hours before maintenance.
2. **Leakage and Foreign Materials**
   - Prevent air/gas leaks and entry of foreign matter.
   - Avoid open flaring without ignition.
3. **Material and Equipment**
   - Use corrosion-resistant materials.
   - Install anti-backfire valves and pressure sensors.

4. Electrical Safety

- Ground all gas-conducting parts.
- Use shielded cables and isolated circuits.

5. Operational Precautions

- Avoid standing near the system during start-up or shutdown.
- Store fuel in fire-proof, ventilated spaces.
- Only trained personnel should operate the system.

6. Post-Shutdown Care

- Vent gas safely before opening.
- Inertize the system with nitrogen after cooling.
- Schedule regular sensor checks and cleaning to prevent slagging and blockage.

Check Your Progress 7.3

Note: a) Use the spaces given below for your answer.

b) Check your answer with those given at the end of the unit.

1) What is the start-up and shut-down time required for the gasifier?

.....

.....

2) What is the maintenance schedule for a gasifier?

.....

.....

3) What are the main fuel storage issues in the gasifier plant?

.....

.....

4) List two reasons why tar management is critical in biomass gasification systems.

.....

.....

Activity 7.2

Visit a nearby place where a gasifier system is fixed and gather information about the safety precautions. Collect all information about the past safety failures (if any) and the reasons for those in the plant.

.....

.....

7.9 LET US SUM UP

In this Unit, you have learned about the concept, principles, and practical aspects of biomass gasification as an efficient and sustainable energy conversion process. Gasification provides an effective means of transforming various types of biomass residues, such as agricultural wastes, wood, and animal residues, into a useful gaseous fuel known as producer gas.

You understood the theory of gasification, including the basic chemical and thermal reactions involved in converting solid biomass into a combustible gas mixture. The unit discussed the different types of gasifiers, such as updraft, downdraft, cross-draft, and fluidised bed systems and their suitability for different feedstocks and applications. The process zones within a gasifier, namely drying, pyrolysis, oxidation, and reduction zones, were explained to illustrate how each contributes to the overall conversion efficiency. The discussion on operating parameters helped you appreciate the influence of temperature, air-fuel ratio, residence time, and feedstock characteristics on gas quality and system performance. The case study on gasification demonstrated practical implementation, challenges, and the potential of gasifiers in real-world agricultural and rural energy systems. You also learned about the cooling and cleaning of gas, which are essential steps for removing impurities such as water vapour, CO_2, H_2S, and particulates to ensure safe and efficient utilisation of producer gas. The section on performance characteristics provided insights into efficiency measurement, gas composition, and operational optimisation.

7.10 KEY WORDS

Bagasse : The fibrous residue is left after extracting sugar-containing juice from plants like sugarcane.

Biofuel : A fuel derived from biomass, such as ethanol, syngas, or producer gas.

Biomass : Material of biological origin, excluding material embedded in geological formations and transformed into fossils. Biomass includes wood, agricultural residues, crops, municipal waste, and animal waste.

Co-firing : The process of using a mixture of two fuels within the same combustion chamber.

Flow Rate : The quantity of fluid passing through a given area (such as a pipe) in a specific time period.

Gasification : A thermal conversion process similar to combustion, in which both heat and a combustible product gas are produced.

Particulates : Fine solid or liquid particles (dust, smoke, mist, fumes, or smog) suspended in air or emissions.

Process Heat : Energy (in the form of hot air or steam) is required for industrial or manufacturing operations.

Producer Gas: A mixture of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), nitrogen (N_2), and small amounts of hydrocarbons like methane (CH_4).

Pyrolysis : The decomposition of complex organic materials by heating in the absence of oxygen produces solid, liquid, and gaseous fuels.

Scrubber : A pollution control device that removes pollutants from a gas stream using a liquid or solid through adsorption or chemical reactions.

Synthesis Gas (Syngas) : Produced from high-temperature gasification (1200°C -1600°C), containing mainly CO and H_2 with a few hydrocarbons.

Volatile : A substance (solid or liquid) that easily vaporises at normal temperatures.

7.11 SUGGESTED FURTHER READINGS/ REFERENCES

- Abubakar, A. B., Oumarou, M. B., Tela, B. M., & Eljummah, A. M. (2019). Assessment of biomass gasification: A review of basic design considerations. *American Journal of Energy Research,* 7(1), 1-14.
- Bhavanam, A., & Sastry, R. C. (2011). Biomass gasification processes in downdraft fixed bed reactors: A review. *International Journal of Chemical Engineering and Applications,* 2(6).
- Bill, T. B. R., & Das, A. (1988). *Handbook of downdraft biomass gasifier engine systems.* Solar Energy Research Institute (SERI), U.S. Department of Energy. SERISP-271-3022, DE88001135.
- Cerone, N., Zimbardi, F., Contuzzi, L., Baleta, J., Cerinski, D., & Skvorčinskienė, R. (2020). Experimental investigation of syngas composition variation along the updraft fixed bed gasifier. *Energy Conversion and Management,* 221, 113116. https://doi.org/10.1016/j.enconman.2020.113116
- Chhiti, Y., & Kemiha, M. (2013). Thermal conversion of biomass: Pyrolysis and gasification – A review. *The International Journal of Engineering and Science (IJES),* 2(3), 75-85.
- Cuong, V. H., & Kong, S.-C. (2013). Performance characteristics of a pilot-scale biomass gasifier using oxygen-enriched air and steam. Fuel, 103, 987-996.
- Isaac, O., Ige, E., & Yunus, I. (2019). Design and performance evaluation of energy-efficient biomass gasifier cook stove using multi fuels. *Journal of Energy Research and Reviews,* 3(4), 1-7. https://doi.org/10.9734/jenrr/2019/v3i430103
- Kumar, A., Jones, D. D., & Hanna, M. A. (2009). Thermo-chemical biomass gasification: A review of the current status of the technology. *Energies*, 2, 55 - 581. https://doi.org/10.3390/en20300556
- McKendry, P. (2002). Energy production from biomass (Part 1): Overview of biomass. *Bioresource Technology,* 83(1), 37 - 46. https://doi.org/10.1016/S0960-8524(01)00118-3
- Milne, T. A., Evans, R. J., & Abatzoglou, N. (1998). *Biomass gasifier tars: Nature, formation and conversion* (NREL/TP-570-25357). National Renewable Energy Laboratory.

- Mishra, S., & Upadhyay, R. K. (2021). Review on biomass gasification: Gasifiers, gasifying mediums, and operational parameters. *Materials Science for Energy Technologies,* 4, 329 - 340.
- Narnaware, S. L., Panwar, N. L., Gupta, T., & Meena, K. K. (2023). Bubbling fluidised bed gasification of biomass: A review on the effect of selected operational parameters. *Biointerface Research in Applied Chemistry,* 13(5), 474. https://doi.org/10.33263/BRIAC135.474
- Pathak, P. S., Khan, T. A., & Sharma, P. (2004). Biomass production, its utilisation and surplus for energy generation in India. In *Proceedings of the National Seminar on Biomass Management for Energy Purpose – Issues and Strategies* (pp. 10 - 35). SPRERI, VV Nagar, India.
- Tezer, Ö., Karabağ, N., Öngen, A., Çolpan, C. Ö., & Ayol, A. (2022). Biomass gasification for sustainable energy production: A review. *International Journal of Hydrogen Energy,* 47(34), 15419 - 15433.
- Wenbin, Z., Hao, L., Irfan, U. H., York, N., Philipp, S., Holger, O., Alexander, S., & Axel, K. (2012). Gas cleaning strategies for biomass gasification product gas. *International Journal of Low-Carbon Technologies,* 7, 69-74.
- Zheng, L., & Furinsky, E. (2005). Comparison of Shell, Texaco, BGL and KRW gasifiers as part of IGCC plant computer simulations. *Energy Conversion and Management,* 46(11-12), 1767-1779.

7.12 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 7.1

1) In the reduction zone, CO_2 and H_2O are partially reduced to carbon monoxide (CO) and hydrogen (H_2) through reaction with carbon at temperatures of 800-1,200ºC. In the pyrolysis zone, these gases contact dry biomass in the temperature range of 400-800 °C and devolatilize the biomass to produce pyrolysis products and residual char.

2) The main aims are to improve the efficiency of energy conversion, to lower emissions, to develop multi-feedstock gasifiers and to reduce costs. The advantages of gasification are to offer greater flexibility, both in the range of possible biomass feedstock and in the end-use of the energy. *For example,* as well as driving a gas turbine, the gas from a gasifier can power a fuel cell to generate electricity, or it can be used to generate steam in a gas boiler, sometimes in combination with natural gas. It also decreases our dependence on conventional fuels and lowers pollutant residues compared to conventional fuels.

3) Cyclone is used to remove ash-rich fines from the gasifier. In Circulating fluidised beds cyclone is also used to recirculate most of the solid and un-gasified particles to the gasifier bed.

Check Your Progress 7.2

1) Various zones in the gasifier systems are drying, pyrolysis, combustion and reduction zones. In the pyrolysis zone, tar and other volatiles are driven off.

2) It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable, and the heat budget of the gasification reaction is impaired. High moisture content decreases the efficiency of the engine and also puts a load on cooling and filtering equipment by increasing the pressure drop across these units.

3) Correct order for gas cooling and cleaning:

   1. Cyclone separator
   2. Wet scrubber
   3. Cloth filter
   4. Gas engine

This sequence ensures coarse dust is removed first, followed by cooling and tar removal, then fine cleaning before the gas enters the engine.

4) Advantages of water scrubbers:

   1. They cool the producer gas and remove dust and tar simultaneously.
   2. They are highly effective in removing fine impurities and soluble gases.

Limitation:

- They require a continuous water supply and regular maintenance due to wastewater and sludge generation.

Check Your Progress 7.3

1) The gas production starts within 10 minutes. Up to 75% capacity can be achieved within 30 minutes, and 100 % in one hour. The gasifier can be shut down practically within 5 minutes. However, a very small amount of gas and water vapour will continue to be released and will have to be vented for some time after shut-down.

2) Scheduled maintenance twice a month is essential for trouble-free, uninterrupted operation of the gasifier. Typically, it takes approximately 6-8 hours.

3) Fuel storage issues are

   - Fuel should be stored in a closed and fire-isolated container.
   - A fire-resistant separation is required between the fuel storage and the gasifier.
   - It is recommended to monitor the temperature in the fuel storage pile, and good ventilation is recommended, preferably natural ventilation.

4) Two reasons why tar management is critical in biomass gasification systems:

   - Tar can condense and clog pipelines, filters, and engines, leading to operational problems and system failure.
   - High tar content damages engines and reduces performance, increasing maintenance requirements and operating costs.

ignou
THE PEOPLE'S
UNIVERSITY