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B.TECH AGRICULTURAL ENGINEERING

AI3702

RENEWABLE ENERGY IN AGRICULTURAL ENGINEERING

Prepared by

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Syllabus

AI3702 RENEWABLE ENERGY IN AGRICULTURAL ENGINEERING L T P C
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COURSE OBJECTIVES:

To impart the fundamental knowledge on the importance of Bio resources, Bio energy and reactors.
To study Slurry handling
To study Bio reactors/ fermentors
To study Alcohol and ethanol production and
To study Energy and Environment

UNIT I BIO RESOURCE – AN INTRODUCTION 9

Bio resource – origin – biomass types and characteristics- biomass conversion technology- Biodegradation - steps in biogas production- parameters affecting gas production- Types of biogas plants- Construction details- operation and maintenance.

UNIT II BIO ENERGY 9

Slurry handling- enrichment and utilization – Biogas appliances- Biochemical characteristics of bio resources- Bioenergetics –Biocatalysis –Kinetics of product formation.

UNIT III BIO REACTORS AND FERMENTORS 9

Bio reactors/ fermentors – Batch type – continuous stirred tank reactors- Biological waste water treatment- Activated sludge process- Down stream processing-Recovery and purification of products.

UNIT IV ALCOHOL PRODUCTION 9

Alcohol ethanol production - Acid hydrolysis - enzyme hydrolysis-Methanol synthesis - Antibiotics- enzymes- principles of thermochemical conversion – combustion - pyrolysis- Gasification – types of gasifiers.

UNIT V ENERGY AND ENVIRONMENT 9

Principles of operation- chemical reaction- cleaning and cooling - Utilization- Improved wood burning stove - Energy plantations- Biomass briquetting - co generation- Impact on Environment – – Bioenergy policy.

TOTAL: 45 PERIODS

TEXTBOOKS:

1. Rai G.D,Non conventional sources of Energy, Khanna publishers, New Delhi, 1995.
2. Bouley James .E & David Follis - Biochemical Engineering Fundamentals Mc Graw-Hill publishing company, Tokyo.1986

REFERENCE:

1. Chawla O.P, Advances in Biogas Technology ICAR publication New Delhi 1986

COURSE OUTCOMES

CO1 The students will be able to understand the concepts of bio energy sources and its applications.

CO2 Gain sufficient knowledge on Bioenergy.

CO3 Know the concept of Bioreactors and Fermentors and their working principles.

CO4 Have knowledge on production of alcohol.

CO5 Utilize these advanced techniques in conserving energy and protecting the environment.

UNIT –I BIORESOURCE – AN INTRODUCTION

Biomass consists of any organic matter of vegetable or animal origin. It is available in many forms and from many different sources e.g. forestry products (biomass from logging and silvicultural treatments, process residues such as sawdust and black liquor, etc.); agricultural products (crops, harvest residues, food processing waste, animal dung, etc.); and municipal and other waste (waste wood, sewage sludge, organic components of municipal solid waste, etc.).

Biomass energy is solar energy stored in the chemical bonds of carbon and hydrogen chains as a result of photosynthesis or the metabolic activity of organisms. Biomass can be referred to as nature's solar battery reflecting its ability to store energy until required, which makes it more predictable and responsive than the sun or wind.

Biomass is the oldest fuel used by mankind and has been its main source of energy for cooking and keeping warm from the dawn of civilisation to the industrial revolution. However, over the last century its use has been supplanted by higher energy density, easier to handle and cheaper fossil fuels such as coal and oil.

Today, biomass (mainly wood) contributes some 10% to the world primary energy mix, and is still by far the most widely used renewable energy source. While bioenergy represents a mere 3% of primary energy in industrialised countries, it accounts for 22% of the energy mix in developing countries, where it contributes largely to domestic heating and cooking, mostly in simple inefficient stoves.

Over the last three decades, issues of energy security, increasing prices of fossil fuels and global warming have triggered a renewed interest in biomass for the production of heat, electricity, and transport fuels. Many countries have introduced policies to support bioenergy, not least as a means of diversifying their agricultural sectors. This has been accompanied by significant developments in conversion processes, with several cleaner, more efficient technologies at the research, development, and demonstration stage, and others already introduced into the market. The biomass resource base is potentially large, and so are the opportunities for its increased use in different energy segments in industrialised and developing countries.

Bioenergy has become increasingly diversified in terms of final uses, and also in terms of resources. While biomass in the past was very much limited to woody feedstock, today's bioenergy landscape includes virtually all of the biomass types available, ranging from food industry residues (waste cooking oil, tallow) to energy crops such as corn, sugar-cane, and Miscanthus. New conversion technologies are being developed to account for the varied physical nature and chemical composition of the feed stocks available, as well as the energy service required. There is also growing interest and research in the production of chemicals from biomass, possibly in conjunction with the production of energy. The multi-functional role of biomass, in terms of both the products and services it might provide, offers an opportunity to generate value beyond energy products.

With serious concern globally and in India on the use of fossil fuels, it is important for India to start using renewable energy sources. India is the seventh largest country in the world spanning 328 million hectares and amply bestowed with renewable sources of energy.

Among the renewable energy sources, biomass plays a vital role especially in rural areas, as it constitutes the major energy source to majority of households in India. India produces about 450-500 million tonnes of biomass per year. Biomass provides 32% of all the primary energy use in the country at present.

Biomass is defined as the organic matter derived from biological materials such as plants, animals, microorganisms and municipal wastes.

Reasons for utilizing biomass

Readily available and renewable.Non-fossil forms of fixed carbon are not depletable, in contrast to fossil fuels such as coal, oil, petroleum fuels and natural gas. Biomass is available in large quantities and provides a raw material for conversion to major supplies of synthetic fuels

Combining waste disposal and energy recovery processes offers recycling opportunities as well as improved disposal technology, often at low cost. Clean and nearly pollution free combustion. Energy and capital requirement for production is low.

Characterization of biomass

Detailed and accurate characterization of biomass feedstock, intermediates, and products is a necessity for any biomass-to-biofuels conversion.

Understanding how the individual biomass components and reaction products interact at each stage in the process is important for researchers.

Typical biomass components

(i)Cellulose

Cellulose is an important structural component of the primary cell wall of green plants, many forms of algae and the oomycetes.

(ii)Hemicellulose

In almost all terrestrial plant cell walls.

(iii)Lignin

Plant cell walls

(iv)Starch

Organic chemical produce all green plants

(v)Proteins

Biomolecules and macromolecules

Cellulose, hemicellulose, and lignin are universally found in many kinds of biomass, and are the most plentiful natural carbon resources on Earth.

Total Solids

A way to determine the moisture content within the sample.

Ash Determination

The amount of inorganic or mineral material present in the sample.

Exhaustive Ethanol and Water Extractable:

The removal of non-structural material from the biomass sample to prevent interferences during other analyses, as well as free sugar determination.

Structural Carbohydrates

The determination of glucose, xylose, galactose, arabinose and mannose concentrations in the sample; used to determine cellulose and hemicellulose concentrations in the biomass.

Acetyl Content

Acetic acid concentration in the sample, may also include formic and levulinic acid content depending on the feedstock.

Lignin

Determination of the structural plant material that does not contribute to the sugar content in the sample.

Starch Content

Represents the readily available source of sugar within some feedstock.

Ethanol Content

Analysis of fermentation broths using gas chromatography.

Bomb Calorimetry

The determination of the sample's calorific value.

Biomass Characterization

The viability and feasibility of bio-energy generation from agricultural biomass depends upon the characteristics of biomass available. Biomass could be employed for energy conversion by means of different processes, such as chemical, biochemical, thermal-chemical etc. The process choice specifically depends on the biomass characteristics; therefore biomass characterization is essential to study various biomass related properties, fuel value, ash handling, combustion, information for design, development and operation of biomass conversion system.

Physical properties

Bulk density, Particle size distribution, Particledensity, Angle of repose, Heatcapacity, Thermal conductivity.

Bulk density

Same as particle density, but volume include void space.

Particle density

Measure of bio mass weight per unit volume (kg/m^3)

Most common device – pycnometer

Particle size distribution

Bio mass need to be size reduced if they are used for any conversion. Bio mass of less then 10mm in size are normally used in conversion process. Measured using sieve analysis.

Angle of repose

Defined as internal angle between the surface of pile and the horizontal surface. Factor affecting angle of repose are, density, surface area, shape of the particle, co-eff of friction of material. Important for designing equipment for bio mass storage (silos), hopper, width of belt in belt conveyer.

Angle of friction

It is the, on other hand, is that angle with which a pile of biomass will slide when raised from the horizontal. One can observe, bio mass will slide easily (lower angle) in smooth surface rather than rough surface. Design of conveying system and hopper.

Heat capacity

Ratio of amount of heat energy transferred to the material TO resulting increasing in temperature of the material. Unit- joules/ kelvin Limited research in this area.

Thermal conductivity

Ability of the material to conduct or transfer heat.If more TC then more heat transfer ability. Low TC used as insulation. Unit of Thermal conductivity - W/m – K

The three sets of commonly used biomass characterization related to thermal conversion are proximateanalysis, Ultimateanalysis, heating value analysis,

Proximate analysis

Include measurement of moisture content (mc), volatile combustible matter (VCM), fixed carbon (FC) and ash.Mc high as 99% for aquatic biomass such as algae and low as 10% for some field crops.

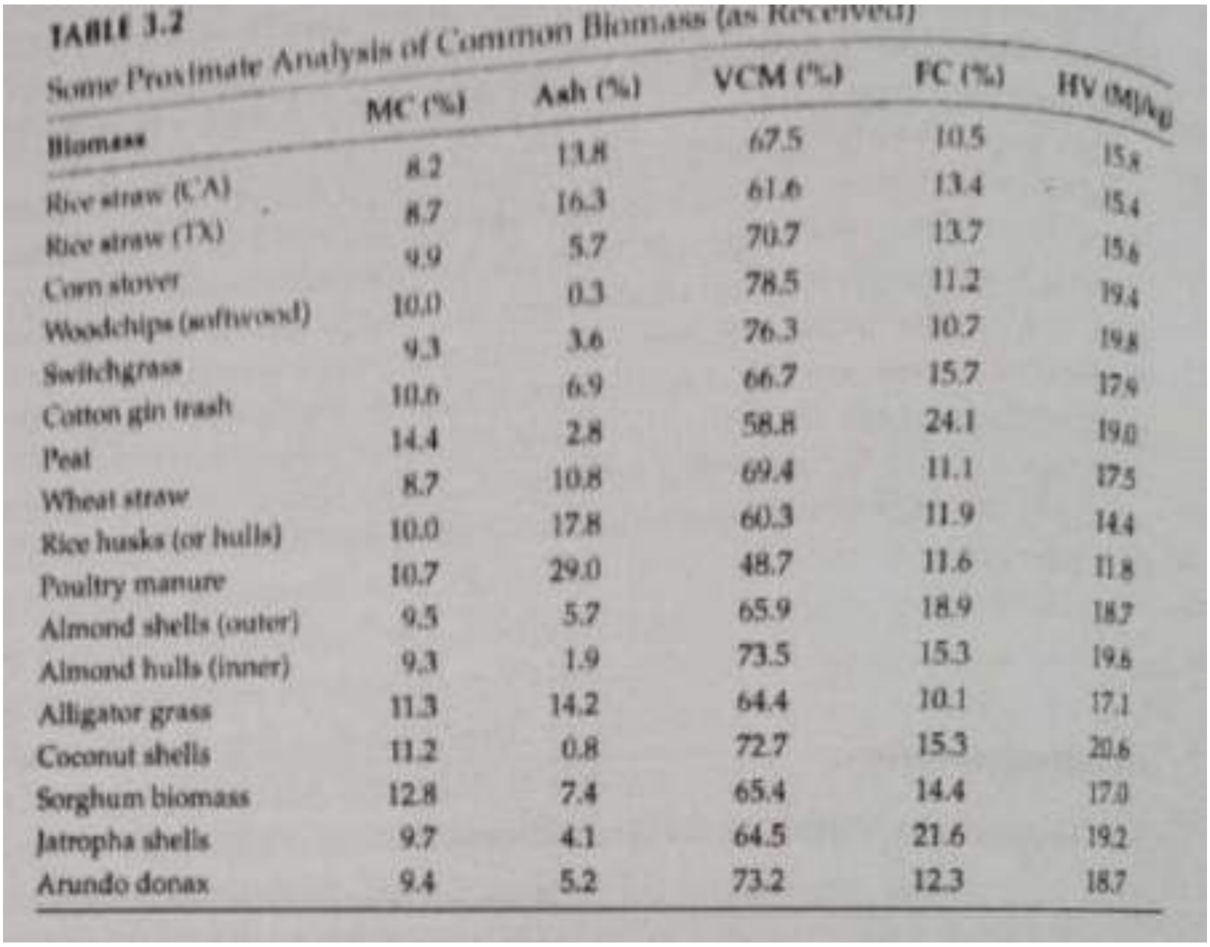


TABLE 3.2
Some Proximate Analysis of Common Biomass (as Received)

Biomass	MC (%)	Ash (%)	VCM (%)	FC (%)	HV (MJ/kg)
Rice straw (CA)	8.2	13.8	67.5	10.5	15.8
Rice straw (TX)	8.7	16.3	61.6	13.4	15.4
Corn stover	9.9	5.7	70.7	13.7	15.6
Woodchips (softwood)	10.0	0.3	78.5	11.2	19.4
Switchgrass	9.3	3.6	76.3	10.7	19.8
Cotton gin trash	10.6	6.9	66.7	15.7	17.9
Peat	14.4	2.8	58.8	24.1	19.0
Wheat straw	8.7	10.8	69.4	11.1	17.5
Rice husks (or hulls)	10.0	17.8	60.3	11.9	14.4
Poultry manure	10.7	29.0	48.7	11.6	11.8
Almond shells (outer)	9.5	5.7	65.9	18.9	18.7
Almond hulls (inner)	9.3	1.9	73.5	15.3	19.6
Alligator grass	11.3	14.2	64.4	10.1	17.1
Coconut shells	11.2	0.8	72.7	15.3	20.6
Sorghum biomass	12.8	7.4	65.4	14.4	17.0
Jatropha shells	9.7	4.1	64.5	21.6	19.2
Arundo donax	9.4	5.2	73.2	12.3	18.7

Volatile combustion matter (VCM)

Bone dry sample placed in platinum crucible with close fitting cover and placed in tube furnace.950 +- 20oCExposed for 7min then celled and re- weighted Loss in weight is VCM.(V1-v2/v1) x 100VCM responsible for more combustible gas during conversion.

FC and ASH

After measuring VCM. Open the cap and set the furnace temp as 600^{o}C for 1hr.Ensure no carbon left. Then re weight, it is the ash. Difference between the ash content and VCM is the FC.

%ASH = 100 - %VCM - %FC.FC is more important; it is the primary element for making liquid bio fuels.

Ultimate analysis

Measure of component of bio mass such as C, H, O, Nitrogen (N), Sulfur(S) and Ash. Elementalanalyzers C vary from low (poultry) of 27% to high of 49.5 %(peat).

The major challenges involves in biomass characterization for bio-energy production are as follows:

Nature of biomass feed stocks,

Multiphase conversion processes,

Typeof bio-fuel,

Technological advancement,

Experimentvalidation,

Processoptimization,

By-products utilization

Biomass conversion technology

In many ways biomass is a unique renewable resource.it can be stored and transported relatively easily in contrast to renewable options such as wind and solar, which create intermittent electrical power that requires immediate consumption and a connection to the grid. It has a cost. With the exception of waste and residues, the cost of biomass often represents a significant share (usually of the order 50-90%) of the production cost of bioenergy. This makes the economics of bioenergy fundamentally different from that of other renewable energy options that mostly rely on free resources (e.g. wind, sunlight, geothermal heat, wave, etc.).One or more conversion steps are needed to transform raw biomass into consumable bioenergy products and services. As it grows, plant biomass captures solar energy and converts it (through photosynthesis) to chemical energy stored in the chemical bonds of its molecular constituents. This chemical energy can be either directly released as heat via combustion (and subsequently transformed into power via an engine or turbine) or converted into a variety of marketable intermediate chemical and energy products. The latter biomass-derived energy products can be solid (chips, pellets, charcoal, etc.), liquid (biodiesel, bioethanol, etc.) or gaseous (biogas, synthesis gas, hydrogen, etc.) that, in turn, can be used in a variety of energy applications including use as transport fuels. Finally, biomass is a resource that is extremely varied in nature, which is again unlike all other renewable energy resources (e.g. the sunlight spectrum is the same all around the world). This requires specific technologies to be developed for each case, as explained in the following section.

A bioenergy chain, or route, consists of a series of conversion steps by which a raw biomass feedstock is transformed into a final energy product (heat, electricity, or transport biofuel). There are many potential bioenergy chains as a result of the wide range of raw biomass feedstocks (wood, grass, oil, starch, fat, etc.) and the variety of possible end-uses.

Different conversion technologies have been developed that are adapted to the different physical natures and chemical compositions of feed stocks, as well as to the energy service required (heat, electricity, transport fuel). While some routes are straightforward (e.g. direct combustion of forest wood for heat production), others necessitate several pre- treatment, upgrading and conversion steps, such as those required for the production of liquid fuels that can be used in an internal combustion engine.

Three main classes of conversion routes can be identified. Thermochemical conversion, by which biomass undergoes chemical degradation induced by high temperature. The four thermochemical routes are combustion, gasification, pyrolysis, and torrefaction which differ mainly in their temperature ranges, heating rate and amount of oxygen present in the reaction. Physicochemical conversion is used to produce liquid fuels (biodiesel or vegetable oil) from oil crop (rapeseed, soybean, Jatropha, etc.) by oil extraction possibly followed by a trans esterification process. Biological routes use living micro-organisms (enzymes, bacteria) to degrade the feedstock and produce liquid and gaseous fuels. Biological routes are numerous, key mechanisms being fermentation from sugar (sugar-cane, sugar-beet, etc.), starch (corn/maize, wheat, etc.) and lignocellulosic (grass, wood, etc.) feedstock, anaerobic digestion (mostly from wet biomass), and the more recent bio-photochemical routes (e.g. hydrogen production using algae), which require the action of sunlight.

Biomass Pre-treatment and Upgrading Technologies

Although it has the great advantage of being a renewable source of energy, biomass has a number of disadvantages when compared with fossil fuels. It has a lower energy density (up to five times lower per unit volume) and is more variable in its physical nature, making handling, transport and storage more complex and more expensive than for fossil fuels. Also, the chemical composition and moisture content of biomass feed stocks may vary considerably, which may require pre- treatment in order to meet the requirements for quality and homogeneity of many conversion technologies. For these reasons, biomass pre-treatment (or upgrading) techniques are used that convert raw biomass into easier to handle, denser and more homogeneous (solid or liquid) fuels, in order to reduce supply chain cost and increase the efficiency and reliability of downstream processes.

Increasing the energy density of biomass may be attractive if it is necessary to decouple bioenergy production from its point of use, due to the increasing cost of transport. The main upgrading technologies used to increase the energy density of the biomass are, in order of development status: pelletisation, pyrolysis, torrefaction, and hydrothermal upgrading.

Pelletisation

Pellets, which are simply made by compressing comminuted small particles of solid biomass, have become a common fuel in developed countries, both in households (in the increasingly popular pellet boilers) and industry. The adoption of quality standards is contributing to a rise in the use of pellets and their international trade. Pellets hold promise for supplying large volumes of standardised solid fuel, in particular for heating applications where they already represent a cost competitive alternative to fossil fuels such as heating oil and gas.

However, pellets tend to absorb moisture during transport and storage, which can significantly reduce their net calorific value. This calls for various mitigation measures along the supply chain, including quality control. Today, pellets are mostly produced from sawdust, a co-product of sawmills, which may be a limiting factor in terms of the volume of pellets that can be easily introduced into the market.

Pyrolysis and hydrothermal upgrading

Pyrolysis is the controlled thermal decomposition of biomass occurring at around 500°C in the absence of oxygen (anaerobic environment) that produces a liquid bio-oil, a mixture of gas (syngas) and charcoal (biochar). There are two main types of pyrolysis processes: fast and slow. These are characterised by different residence times in the pyrolysis reactor, and lead to different proportions of the liquid, gas, and solid fractions. While slow pyrolysis favours the production of bio-char, which can be substituted in any applications using coal, fast pyrolysis is given more attention as it maximises the production of bio-oil. Bio-oil should be cheaper to handle, store and transport compared to raw solid biomass. Also, the energy density (per unit volume) of bio-oil is higher than that of pellets or torrefied biomass, which gives it a competitive advantage in terms of transport cost. Potentially, bio-oil could be upgraded and used as a transport fuel, providing an efficient route to fuels that could be closely integrated with a petroleum infrastructure (see Section 3.6.3). Bio-oils can also be produced by liquefaction in the presence of water, and possibly additional solvents (e.g. methanol), at high pressure (120-200 atmospheres) and relatively mild temperatures (300-400°C).

This process is known as hydrothermal upgrading (HTU). One attractive feature of this process is that wet biomass can be used directly and that the bio-oil is less soluble in water in contrast to the bio-oil from fast pyrolysis. However, in spite of these advantages and although considerable experience has been gained over recent decades, in particular for fast pyrolysis, these technologies are still at the demonstration stage. Only a few successful pyrolysis demonstration units have been realised (e.g. in Finland and Canada), and both economic and technical issues around quality, consistency and long-term stability of the bio-oil, which tends to degrade over time, remain to be address

Torrefaction

Torrefaction is a high-efficiency thermal process occurring at 200-300°C by which biomass (usually wood) is chemically upgraded into a dry product that resembles coal in appearance. Torrefied biomass has a high energy density and is hydrophobic, which means it can be transported over long distances and stored outside without absorbing any significant amount of water, hence without reducing its calorific value. Torrefied biomass can also be pelletised to further reduce its handling and transportation costs. Torrefied pellets are expected to be even more cost competitive than traditional pellets. The homogeneous and coal-like properties of torrified biomass make it an interesting feedstock in terms of compatibility with a range of conversion technologies. Torrefaction technology is currently at the demonstration stage, but could become commercially available in the near future. This would facilitate access to remote resources, such as residues from forest products industries and forests in remote regions.

Biomass for Heat Applications

The production of heat from biomass is the traditional energy use of biomass. Biomass-to-heat systems are all commercial (see Figure 3-2) and mostly cost-competitive, although the economic case will be context specific and depends on the cost of fossil alternatives.

Combustion

The burning of biomass for heat is the oldest and most common way of converting solid biomass to energy. Because combustion is a straightforward and well understood process, there is a wide range of existing commercial technologies tailored to the characteristics of the biomass and the scale of the application (see Annex 3.2 for a more detailed description of the biomass-fuelled heating systems).

Domestic systems

The direct burning of woody feedstock has been used since the dawn of civilisation and is still by far the biomass conversion technology making the largest contribution to global energy supply (see Annex 4.1). Although modern units, such as increasingly popular pellet boilers, have an efficiency as high as 90%, the vast majority of domestic biomass devices in use are low efficiency (5-30%) traditional cooking stoves found mostly in developing countries (IEA 2008b). The potential for expanding biomass heating in industrialised countries and improving the use of biomass for heating in developing countries is considerable.

District heating and cooling.

Although it is a proven technology, the economic case for biomass-based district heating depends on a number of complex techno economic parameters. Today, biomass-based district heating provides a significant share of the heating requirements in some countries (e.g. northern European countries). Although an economic case can be made for appropriately-scaled district heating networks, the high cost of new heat distribution networks and the difficulty of guaranteeing high overall efficiency are key issues hindering further deployment. Interest in district cooling systems (especially in combination with heat and electricity production, i.e. tri-generation) is on the rise. This could provide an efficient way of providing cooling services and improve the economic viability of biomass schemes through enhanced utilisation of plant and infrastructure

Industrial systems.

An increasing number of boilers in the 0.5-10 MWth range are found in industries that consume large amounts of heat and have large volumes of biomass residues at their disposal. The industrial sector is potentially a large market for biomass heating, but it requires tailored solutions that meet the technical requirements of different industries, e.g. in terms of heating temperatures and flue gas quality

Gasification

The use of gasifiers for direct heat application is mainly confined to emerging countries, while gasification for the production of higher value energy products (e.g. electricity and transport fuel) is of greater importance to developed countries (see Section 3.5.3). Hundreds of smaller size biomass gasifiers (10-500 kWth) are for example, being deployed mainly for intermittently operating thermal applications in China, India and South East Asia with viable pay-backs. However, reliability and maintenance of these units for continuous operation.

Biomass for Power and CHP Applications

There are a multitude of feedstock and conversion technology combinations to produce power and combined heat and power (CHP), albeit at different stages of development and deployment. Figure 3-2 shows the development status of different routes that are explained further in this section. The economic case of a bioenergy option for power and CHP depends not only on the actual technology (capital and operating costs, conversion efficiency, process reliability, economies of scale, etc.), but also crucially on the locally prevailing context for both biomass supply (quality, type,availability and cost) and final energy demand (cost of alternative energy production, heat demand and value, grid accessibility, support policies, etc.). Figure 3-3 and Figure 3-4 compare the capital cost and production cost for the main conversion technologies available for power and CHP applications. The wide range of costs found for most technologies indicates both that economies of scale are important (e.g. for steam turbines) and that most of these technologies are still in their demonstration stage (Stirling Engine, BIG/CC and Organic Rankine Cycle).

Biomass combustion

Biomass-based power plants.

The heat produced by direct biomass combustion in a boiler can be used to generate electricity via a steam turbine or engine. The electrical efficiency of the steam cycle is lower than that of alternative technologies such as gasification-based pathways (see below), but it is currently the cheapest and most reliable route to produce power from biomass in stand-alone applications. In a fragmented biomass supply market, the cost of purchasing large quantities of biomass may increase sharply as the distance to suppliers (and thereby logistical cost) increases.

In this context, the importance of economies of scale for steam-cycle plants has meant that dedicated biomass power plants have generally only proven commercially viable at the larger scale (30-100 MWe) when using low cost feed stocks available in large volumes such as agricultural residues (e.g. bagasse), or wood residues and black liquor from the pulp and paper industry. However, a growing number of viable smaller scale plants (5-10 MWe) using other type of residues (wood, straw, etc.) are found throughout Europe and North America.

MSW waste-to-energy plants.

Municipal solid waste (MSW) is a highly heterogeneous and usually heavily contaminated feedstock, which calls for robust technologies and rigorous controls over emissions, leading to relatively high costs associated with waste-to-energy facilities. Different technologies are available, and the choice usually depends on the degree of separation of the different MSW fractions. The generally uncompetitive cost at which electricity is generated means that, in the absence of an appropriate waste hierarchy and associated incentives, MSW remains a largely unexploited energy resource despite its significant potential in most countries.

Biomass-based cogeneration (CHP) plants.

The principal means to significantly increase the overall efficiency of a power plant (and hence its competitiveness) is to find an economic application for its waste heat. Combined heat and power (CHP) plants, also called cogeneration plants, have typical overall (thermal + electric) efficiencies in the range of 80-90%, provided a good match can be found between heat production and demand (IEA 2008c). This is commonly the case, for example, in the sugar-cane industry.

Co-generation has been shown to reduce the cost of power production by 40-60% for stand-alone plants in the range of 1-30 MWe. However, for domestic and commercial heating applications, the scale of biomass CHP plants is often limited by the total local heat demand and by its seasonal variation, which can significantly affect economic returns unless absorption cooling is also considered (tri-generation).

Distributed cogeneration units.

In the lower capacity range, the Stirling Engine (10-100 kWe) and the Organic Rankine Cycle (ORC) (50-2000 kWe) are promising technologies for distributed cogeneration. Currently at the demonstration stage, improvements are still needed, in particular concerning conversion efficiency, reliability, and cost. Developments in these technologies are, however, not focussing primarily on biomass-fuelled units, although some efforts in this direction have been made in Europe (Germany, Austria, the Netherlands, and Switzerland).

Co-firing

The co-combustion of liquid and solid biomass materials with fossil fuels in thermal processes for heat and power production can be relevant to all scales of operation. Biomass co-firing activities have expanded rapidly in recent years, particularly in Northern Europe, and the most popular approach has involved the direct co-firing of solid biomass with coal in existing large power station boilers. This has proved to be the most cost-effective and most efficient large scale means of converting biomass to electricity and, where relevant, district heating. This is because this approach capitalises on the existing infrastructure of the coal plant and thus requires only minor investment in the biomass pre-treatment and feed-in systems. It also profits from the comparatively higher conversion efficiencies of these coal plants.

However, in spite of the great progress achieved in co-firing over the past decade, biomass properties pose several challenges to coal plants that may affect their operation and lifetime, in particular when a feedstock other than wood is used. This generally limits the amount of biomass that can be co-fired. The alternative option of indirect and parallel co-firing is designed to avoid these issues, but is much more expensive than direct co-firing (see Annex 3.4 for further details on co-firing technologies). Carbon capture and storage (CCS) from fossil-fuelled power plant flue gases is being considered as a measure to reduce greenhouse gas emissions. In this context, CCS can also be applied to co-firing plants, which would enable the capture of carbon from biomass (biotic CCS), resulting in a net negative carbon emission or carbon sink associated with biomass combustion.

Gasification

Gasification is a thermo-chemical process in which biomass is transformed into fuel gas, a mixture of several combustible gases. It has two key advantages over direct combustion. First, gasification is a highly versatile process as virtually any biomass feedstock can be converted to fuel gas with high efficiency. Second, fuel gas can be used directly for heat or power applications or upgraded to syngas for biofuel production (see Figure 3-1 as well as Section 3.6.3 for conversion into liquid biofuels). Thus gasification technology could suit several possible applications in various market segments. In combination with a power-generation device, gasification can offer higher overall conversion efficiencies compared to combustion-based routes. This is particularly true for small-scale plants (30 MWe), gasification based systems are coupled with combined gas and steam turbines, again providing efficiency advantages compared to combustion.

However, such plants require more skilled operation compared to combustion plants, and their efficiency and reliability still need to be fully established. Although several projects based on advanced concepts such as the Biomass Integrated Gasification Combined Cycle (BIG/CC) are in the pipeline in northern Europe, USA, Japan, and India, it is not yet clear what the future holds for large-scale biomass gasification for power generation. Gasification can also co-produce a range of end-products, such as heat and electricity, together with liquid fuels and possibly other products in biorefineries. Such advanced concepts are currently being investigated in research and pilot plants. (See Annex 3.5 for further details).

Anaerobic digestion

Anaerobic digestion is the biological degradation of biomass in oxygen-free conditions. The main product of anaerobic digestion is biogas, a methane-rich gas. Biogas can either be burnt in power generation devices for on-site (co)generation, or upgraded to natural gas standards for injection into the natural gas network as bio methane or for use directly as gaseous biofuel in gas engine-based captive fleets such as buses. Anaerobic digestion can biodegrade virtually all biomass that animals can digest (essentially any biomass excluding woody materials). It is particularly suited to wet feed stocks such as animal manure, sewage sludge from waste water treatment plants, wet agricultural residues and the organic fraction of MSW. Anaerobic digestion also occurs naturally underground in landfills and produces landfill gases which can be collected for use in energy applications. Anaerobic digestion is a well-established commercial technology, although its economic case relies heavily on the availability of very cheap or free feedstock such as sewage sludge, manure and some agricultural residues.

Today, China is by far the biggest biogas producer in the world, with around 18 million farm households using biogas and about 3,500 medium to large-scale digester units (DEFRA 2007). In Europe, specific support mechanisms have resulted in Germany being the leader in this technology, with farm-based units totalling a combined 550 MWe installed capacity in 2006 (i.e. similar to that of a coal power plant). In order to increase productivity, decentralised farm-size units are increasingly relying on supplementary feedstock such as agricultural residues or crops. Sewage sludge digestion and use of landfill gas are both effectively supported by waste disposal fees, which mean that these are globally the most common forms of anaerobic digestion generating energy at present (led by UK, Italy, and Spain). In contrast, deployment of biogas technology in the USA suffers from a reputation for poor reliability (EPA 2008). The key co-product of anaerobic digestion is a nutrient-rich digestate, which can be used as a fertiliser.

However, when using contaminated feedstock, contaminants may end up in the digestate, making it unsuitable for this and difficult to dispose of. Biomass pre-treatment and separation processes to remove these contaminants can help to avoid this, although these are processes which still need to be proven at larger commercial scale. (See Annex 3.6 for more details).

Biofuels for Transport Applications

Biofuels are commonly separated into different ‘generations’ according to their level of development and the feed stocks they use, though there is no universally agreed definition.

1st generation biofuels include mature technologies for the production of bioethanol from sugar and starch crops, biodiesel and renewable diesel from oil crops and animal fats, and bio methane from the anaerobic digestion of wet biomass.

2nd generation biofuels encompass a broad range of novel biofuels based on new feed stocks. These include: - Bioethanol and biodiesel produced from conventional technologies but based on novel starch, oil and sugar crops such as Jatropha, cassava or Miscanthus; - A range of conventional and novel biofuels (e.g. ethanol, butanol, syndiesel) produced from lignocellulosic materials (i.e. fibrous biomass such as straw, wood, and grass). These routes are based on biochemical and thermochemical technologies still at the demonstration stage.

3rd generation biofuels (also called advanced biofuels) generally include biofuel production routes which are at the earlier stages of research and development or are significantly further from commercialisation (e.g. biofuels from algae, hydrogen from biomass)

Bioethanol from sugar and starch crops.

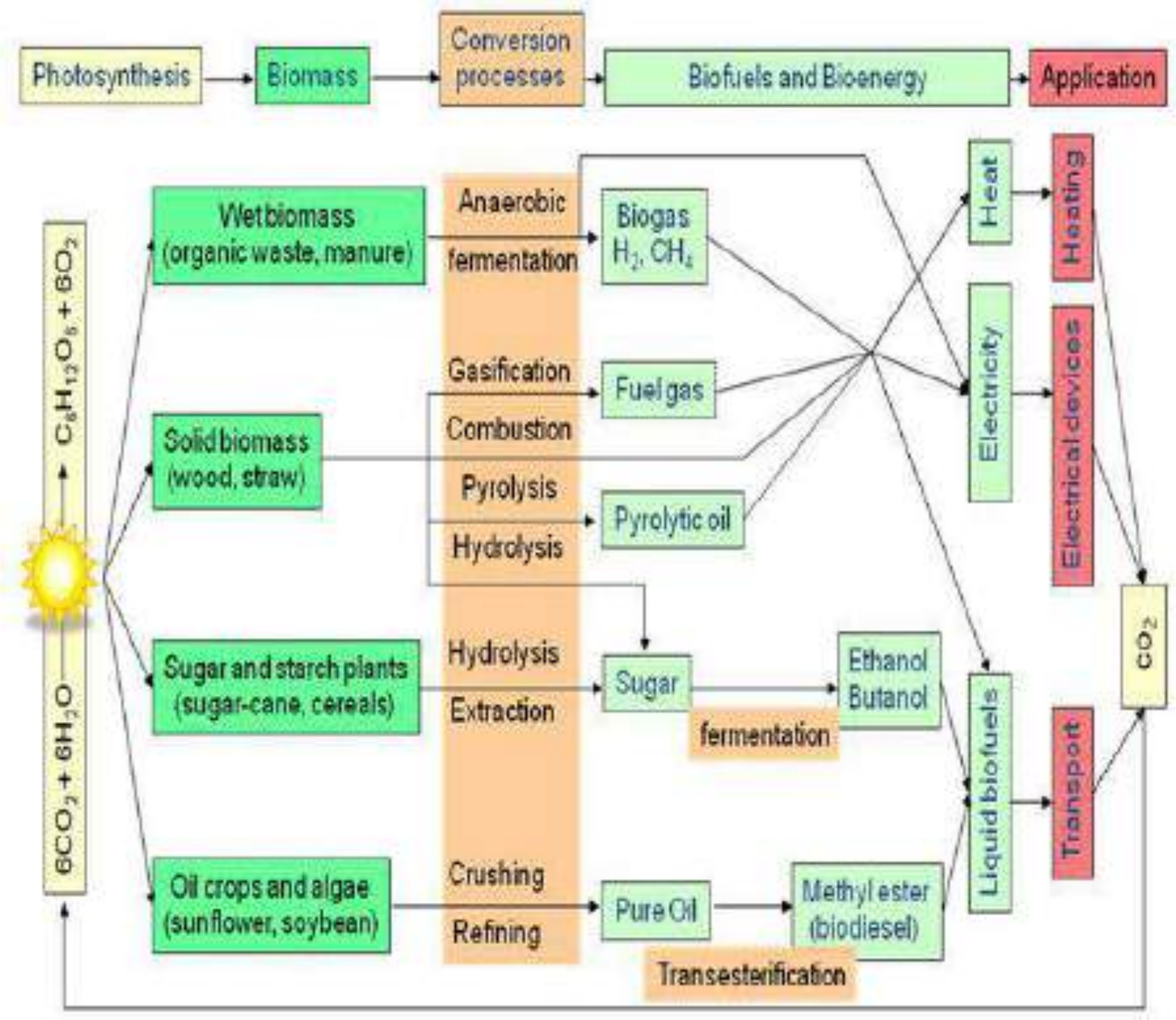
The biological fermentation process used to produce ethanol from sugars extracted from sugar and starch crops is technically mature and commercially available. However, technical improvements can still be made to commercial ethanol production routes, e.g. improved enzymes to convert starch to sugars (hydrolysis), improved bacteria (fermentation), water separation methods, process and plant optimisation, and greater value-added co-products (e.g. development of biorefineries – see Section 3.7).

Biodiesel and renewable diesel from oil crops, waste oils and fats.

Bioethanol from sugar and starch crops, Biomass to biofuels

Bioethanol from lignocellulosic feedstocks, Biomass-to-Liquids (BTL)

Bio methane, Biofuels from algae, Biorefineries,Biomass-to-heat,Biomass-to-power and CHP,



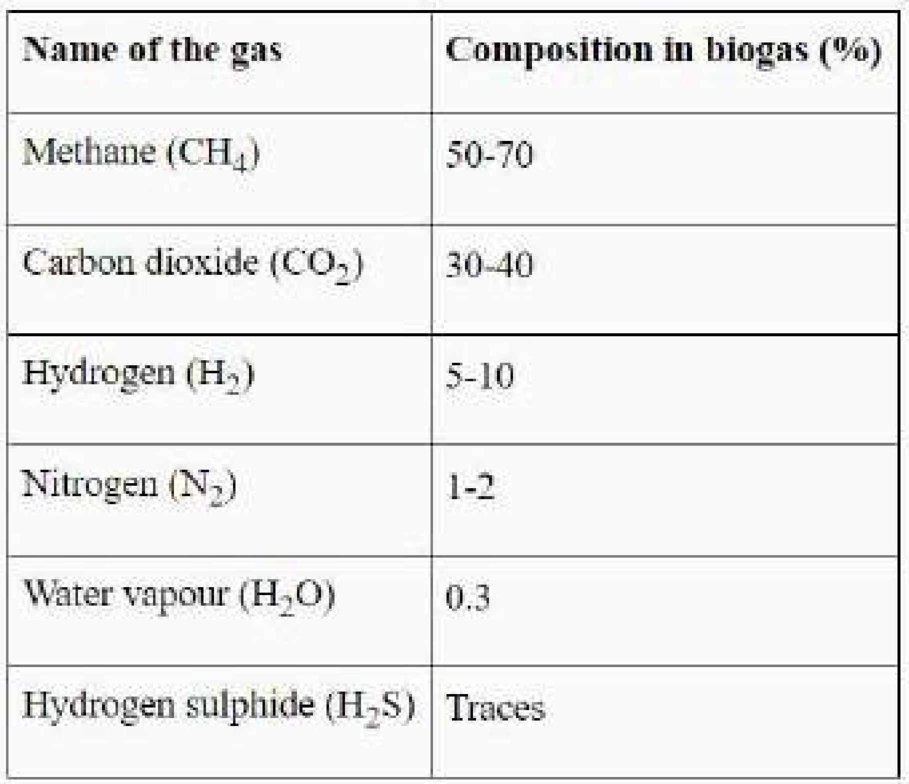
Flow chart of Biomass conversion technology

Biogas production

Biogas is the mixture of gases produced by the breakdown of organic matter by microorganisms in the absence of oxygen (anaerobically).

Biogas, a mixture containing 55-65 % methane, 30-40 % Co_2 and the rest being the impurities (H_2, H_2S, and some N_2), can be produced from the decomposition of animal, plant and human waste. It is a clean but slow burning gas and usually has a colorific value-between 5000 to 5500 kcal/kg.

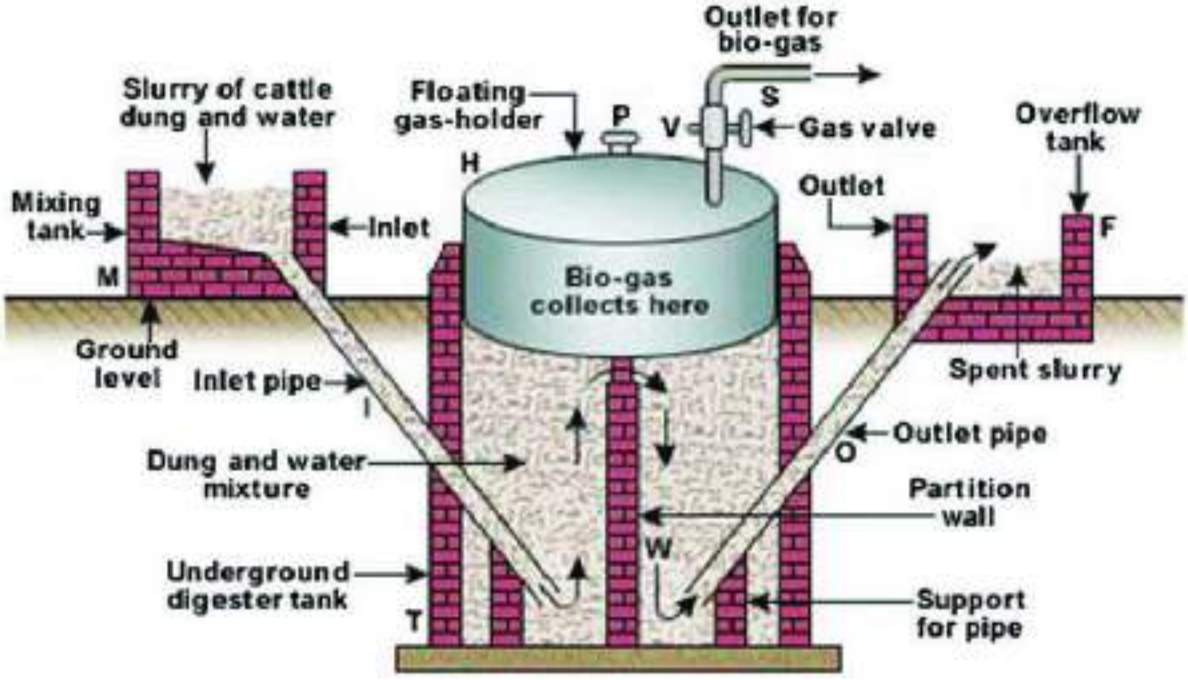
Methane is a combustible gas. The energy content of biogas depends on the amount of methane it contains.



Name of the gas	Composition in biogas (%)
Methane (CH_4)	50-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water vapour (H_2O)	0.3
Hydrogen sulphide (H_2S)	Traces

A few other materials through which biogas can be generated are, Algae, crop residues (agro-wastes), garbage kitchen wastes, paper wastes,Sea wood, human waste, waste from sugarcane refinery, water hyacinth etc., apart from the abovementioned animal wastes.

Any cellulosic organic material of animal or plant origin, which is easily biodegradable, is a potential raw material suitable for biogas production.



Microbiology of biogas production

The production of biogas from organic material under anaerobic condition involves sequence of microbial reactions.

During the process complex organic molecule present in the biomass are broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria.

The resultant products are then used to produce methane byanother category of bacteria. The biogas production process involves three stages namely:

- Hydrolysis
- Acid formation and
- Methane formation

The process of degradation of organic material in every step is done by range of bacteria, which are specialized in reduction of intermediate products formed.

The efficiency of the digestion depends how far the digestion happens in these three stages. Better the digestion, shorter the retention time and efficient gas production.

Hydrolysis

The complex organic molecules like fats, starches and proteins which are water insoluble contained in cellulosic biomass are broken down into simple compounds with the help of enzymes secreted by bacteria.

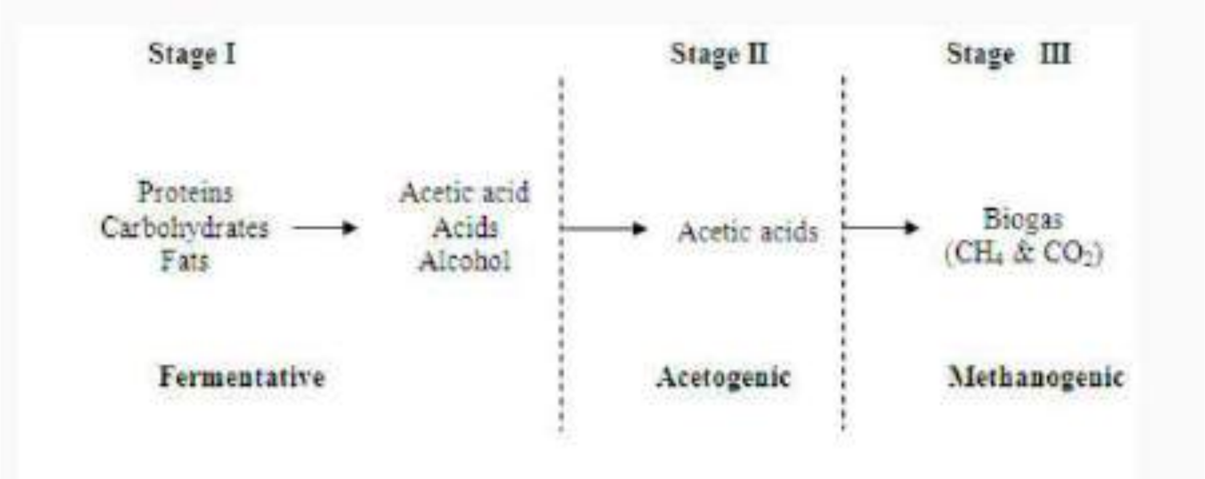
This stage is also known as polymer breakdown stage (polymer to monomer). The major end product is glucose which is a simple product.

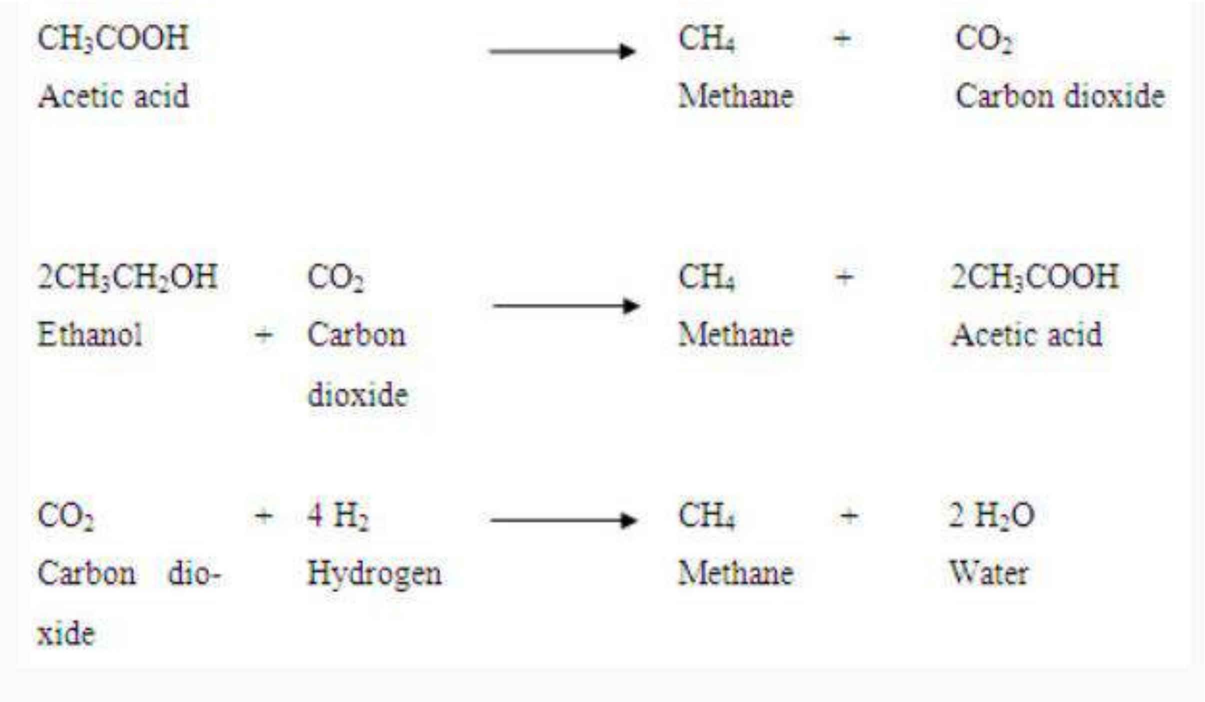
Acid formation

The resultant product (monomers) obtained in hydrolysis stage serve as input for acid formation stage bacteria. Products produced in previous stage are fermented under anaerobic conditions to form different acids. The major products produced at the end of this stage are acetic acid, propionic acid, butyric acid and ethanol.

Methane formation

The acetic acid produced in the previous stages is converted into methane and carbon dioxide by a group of microorganism called “Methanogens”. In other words, it is process of production of methane by methanogens. They are obligatory anaerobic andvery sensitive to environmental changes. Methanogens utilize the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. It is these components that make up the majority of the biogas emitted from the system.





$$\underset{\text{Acetic acid}}{CH_3COOH} \longrightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Carbon dioxide}}{CO_2}$$

$$\underset{\text{Ethanol}}{2CH_3CH_2OH} + \underset{\text{Carbon dioxide}}{CO_2} \longrightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Acetic acid}}{2CH_3COOH}$$

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Hydrogen}}{4\,H_2} \longrightarrow \underset{\text{Methane}}{CH_4} + \underset{\text{Water}}{2\,H_2O}$$

Factors involved in biogas production

C/N ratio

The ratio of carbon to nitrogen present in the feed material is called C:N ratio. It is a crucial factor in maintaining perfect environment for digestion. Carbon is used for energy and nitrogen for building the cell structure. Optimum condition for anaerobic digestion to take place ranges from 20 to 30:1. This means the bacteria use up carbon about 20 to 30 times faster than they use up nitrogen.

When there is too much carbon in the raw wastes, nitrogen will be used up first and carbon left over. This will make the digestion slow down and eventually stops.

On the other hand if there is too much nitrogen, the carbon soon becomes exhausted and fermentation stops. The nitrogen left over will combine with hydrogen to form ammonia. This can kill or inhibit the growth of bacteria specially the methane producers.

Temperature

Temperature affects the rate of reaction happening inside the digester. Increase in the ambient temperature increases the rate of reaction thus increasing the biogas production as well.

Methane bacteria work best at a temperature of 35^0 – 38^0 C. The fall in gas production starts at 20^0C and stops at a temperature of 10^0C.Studies showed that 2.25 m^3 of gas was produced from 4.25m^3 of cattle dung every day when the digester temperature was 25^0C. When the temperature raised to 28.3^0C the gas production was increased by 50 per cent to 3.75 m^3 per day.

Retention time

It is the theoretical time that particular volume of feedstock remains in the digester. In other words, retention time describes the length of time the material is subjected to the anaerobic reaction. It is calculated as the volume of digester divided by the feedstock added per day and it is expressed in days.

Under anaerobic condition, the decomposition of the organic substances is slow and hence need to keep for long time to complete the digestion. In case of Indian digesters, where the feed stock is diluted with equal composition, so demarcation prevails between solid and liquid. In this case, biomass in the form of bacteria is washed out; hence the solid retention time (SRT) is equal to hydraulic retention time (HRT).

Loading rate

Loading rate is defined as the amount of raw material fed to the digester per day per unit volume.If the reactor is overloaded, acid accumulation will be more obviously affecting daily gas production. On the other hand, under loading of digester have negative impact in designed gas production.

Toxicity

Though small quantities of mineral ions like sodium, potassium stimulates the growth of bacteria, the high concentration of heavy metals and detergents have negative impact in gas production rate.

Detergents like soap, antibiotics, and organic solvents are toxic to the growth of microbes inside the digester. Addition of these substances along with the feed stock should be avoided.

pH or hydrogen ion concentration

To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester. pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the latter 2-3 weeks times, the pH increase as the volatile acid and N_2 compounds are digested and CH_4 is produced.

The digester is usually buffered if the pH is maintained between 6.5 and 7.5. In this pH range, the micro – organisms will be very active and digestion will be very efficient.

If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline. Both these are detrimental to the methanogenic (Methane production) organisms.

Total solid content

The raw cow dung contains 80-82% of moisture. The balance 18-20% is termed as total solids. The cow dung is mixed usually in the proportion of 1:1 in order to bring the total solid content to 8-10%. This adjustment of total solid content helps in digesting the materials at the faster rate and also in deciding the mixing of the various crop residues as feed stocks in biogas digester.

Feed rate

One of the prerequisites of good digestion is the uniform feeding of the digester so that the micro – organisms are kept in a relatively constant organic solids concentration at all times. Therefore the digester must be fed at the same time every day with a balanced feed on the same quality and quantity.

Diameter to depth ratio

Studies reveal that gas production per unit volume of digester capacity was maximum, when the diameter to depth ratio was in the range of 0.66 to 1.00. One reason may be that because in a simple unstirred single stage digester the temperature varies at different depths. The most activity digesting sludge is in the lower half of the digester and this is less affected by changes in night and day temperature.

Nutrients

The major nutrients required by the bacteria in the digester are, C, H_2, O_2, N_2, P and S, of these nutrients N_2 and P are always in short supply. Therefore to maintain proper balance of nutrients an extra raw material rich in phosphorus (night soil, chopped leguminous plants) should be added along with the cow dung to obtain maximum production of gas.

Degree of mixing

Bacteria in the digester have very limited reach to their food, it is necessary that the slurry is properly mixed and bacteria get their food supply. light mixing improves the fermentation, however a violent slurry agitation retards the digestion.

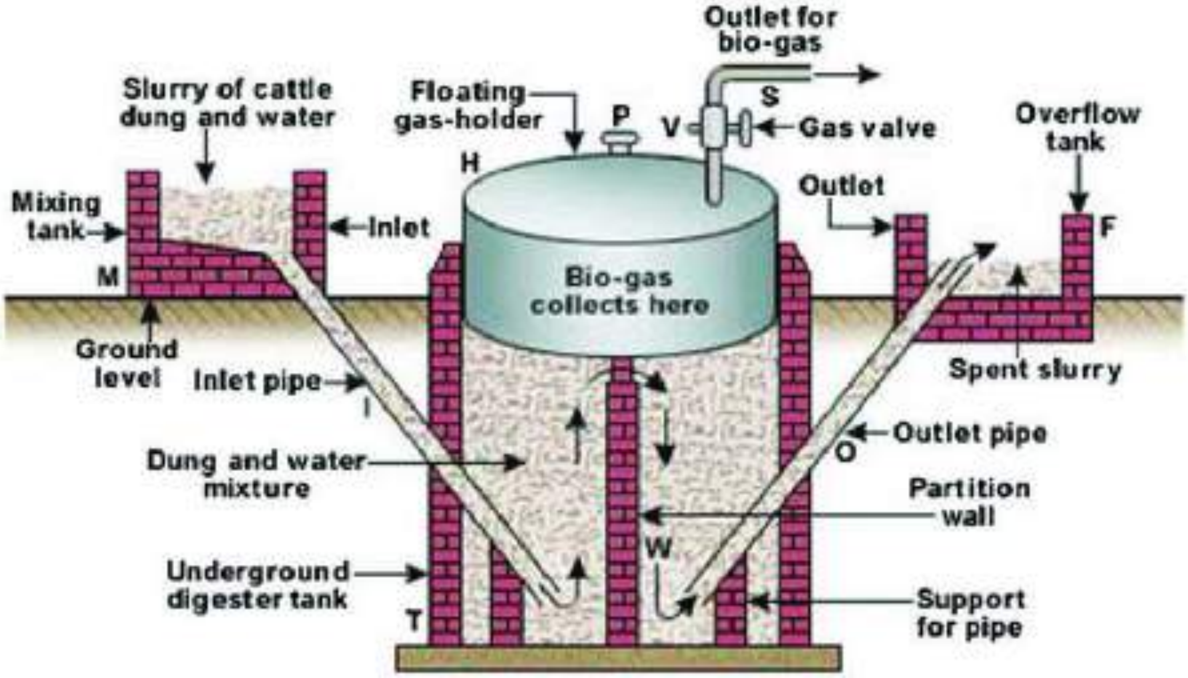
Type of feed stocks

All plant and animal wastes may be used as the feed materials for a digester. When feed stock is woody or contains more of lignin, then digestion becomes difficult.

To obtain as efficient digestion, these feed stocks are combined in proportions. Pre-digestion and finely chopping will be helpful in the case of some materials. Animal wastes are predigested. Plant wastes do not need pre-digestion. Excessive plant material may choke the digester.

Structure of Biogas plants

In a biogas plant, the feedstock is mixed with water and fed in to a tank, where feedstock goes through number of reaction producing biogas. The mix of dung and water is called slurry. After biogas production, the slurry comes out of the tank and is rich in nutrients and can be used as fertilizer. The biogas produced in the plant is stored in a gas holder.



Components of Biogas plants

Digester: This is the fermentation tank and is built partially or fully underground. It is generally cylindrical in shape and made up of bricks and cement. It holds slurry within it for the period of digestion for which it is designed.

Gas Holder: After release of methane from the digester, it is controlled in a tank called gas holder. It may be a floating drum or a fixed dome. The floating dome is made of steel or iron while the fixed dome is made of cement and concrete. The gas connection is taken from the top of this gas holder. The gas is taken through pipes to the burners.

Slurry Mixing (Inlet): Dung is mixed with water and fed into the digester from the inlet.

Slurry pit (Outlet): An outlet from the digester, from where slurry is taken out to the field.

Classification of Biogas Plants

Biogas plants are mainly classified as:

1. Based to the process: Continuous and batch types
2. Based on dome type
3. Based on drum type

Based on the process

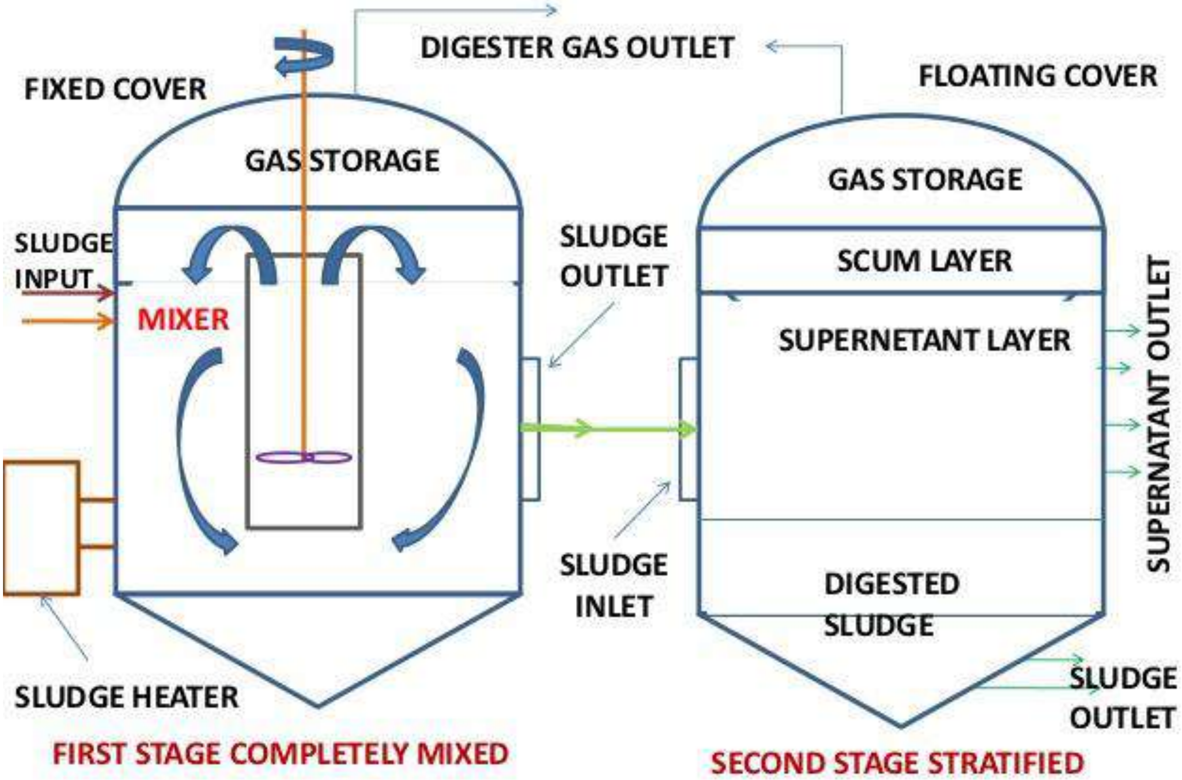
1. Continuous type plant
    (i) Single stage process (ii) Double stage process
2. Batch type Plant

Continuous Type Plant

There is a single digester in which raw material is charged regularly and the process goes on without interruption except for repair and cleaning etc. It is thoroughly mixed with the digesting mass where dilution prevents souring and the biogas production is maintained. The continuous process may be completed in a single stage or separated into two stages. Single stage process – The entire process of conversion of complex organic compounds into biogas is completed in a single chamber. This chamber is regularly fed with the raw materials while the spent residue keeps moving out.

Double stage process – In double stage process, the first stage of acid production is carried out in a separate chamber and only the diluted acids are fed into the second chamber.

Where bio-methanation takes place and the biogas can be collected from the' second chamber. The main features of continuous plant are that: It will produce as continuously. It requires small digestion chambers. It needs lesser period for digestion. It has less problems compared to batch type and it is easier in operation.



SCHEMATIC OF TWO-STAGE DOGESTION PROCESS

Batch Type Plant

The feeding is between intervals, the, plant is emptied once the process of digestion is complete. In this type, a battery of digesters are charged along with lime, urea etc. and allowed to produce gas for 40-50 days. The biogas supply may be utilized after 8-10 The main features of the batch plant are: Thegas production is intermittent, depending upon the clearing of the digester. It needs several digesters or chambers for continuous gas production Batch plants are good for long fibrous materials. This plant needs addition of fermented slurry to start the digestion process. Thisplant is expensive and has problems

Based on dome and drum types

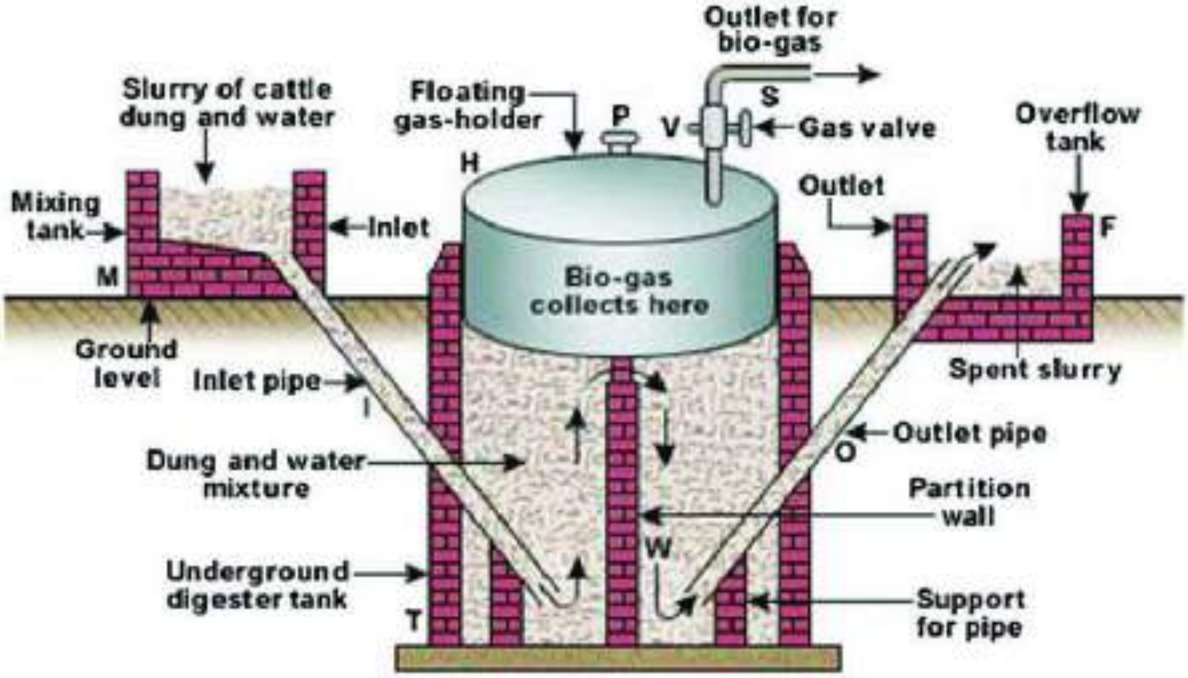
Floating gasholder digester (KVIC)

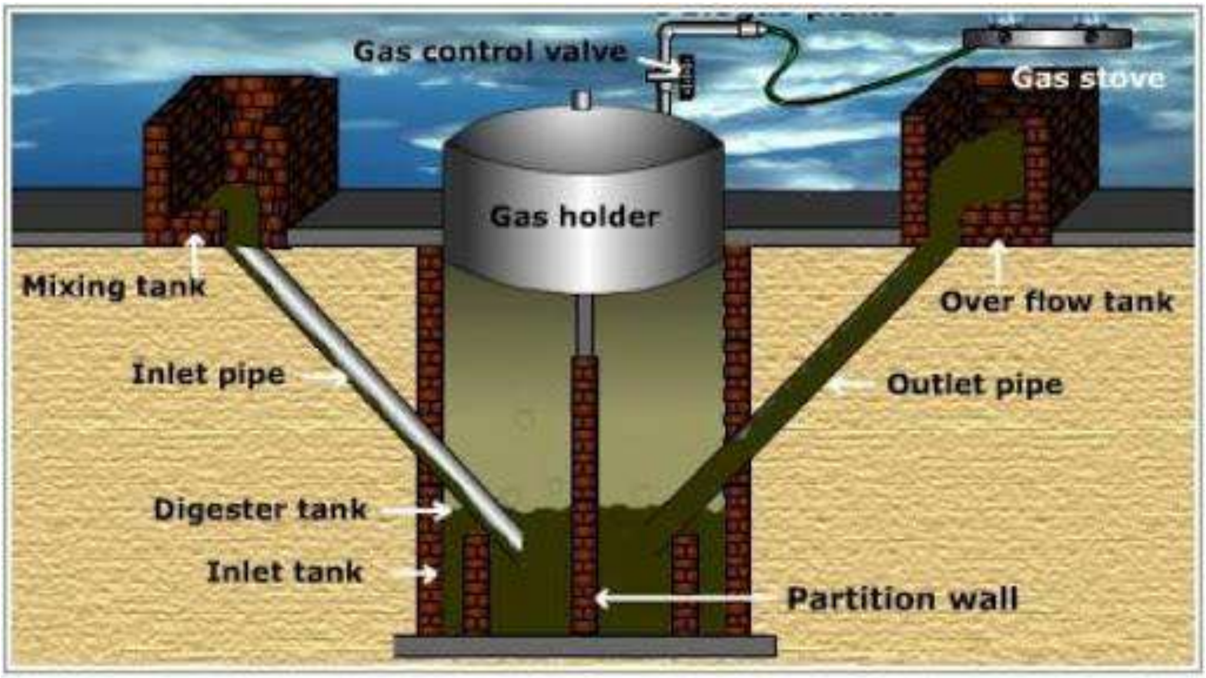
Fixed dome digester

Floating gasholder digester (KVIC)

This type was developed in India and is usually made of masonry. It runs on a continuous basis and uses mainly cattle dung as input material. The gasholder is usually made of steel, although new materials such as Ferro cement and bamboo-cement have already been introduced. FRP materials are also used.

The original version of this floating gasholder digester was a vertical cylinder provided with partition wall except for the small sizes of 2 and 3 m^3 of gas per day. The main characteristic of this type is the need for steel sheets and welding skill.Khadi & Village Industries commission



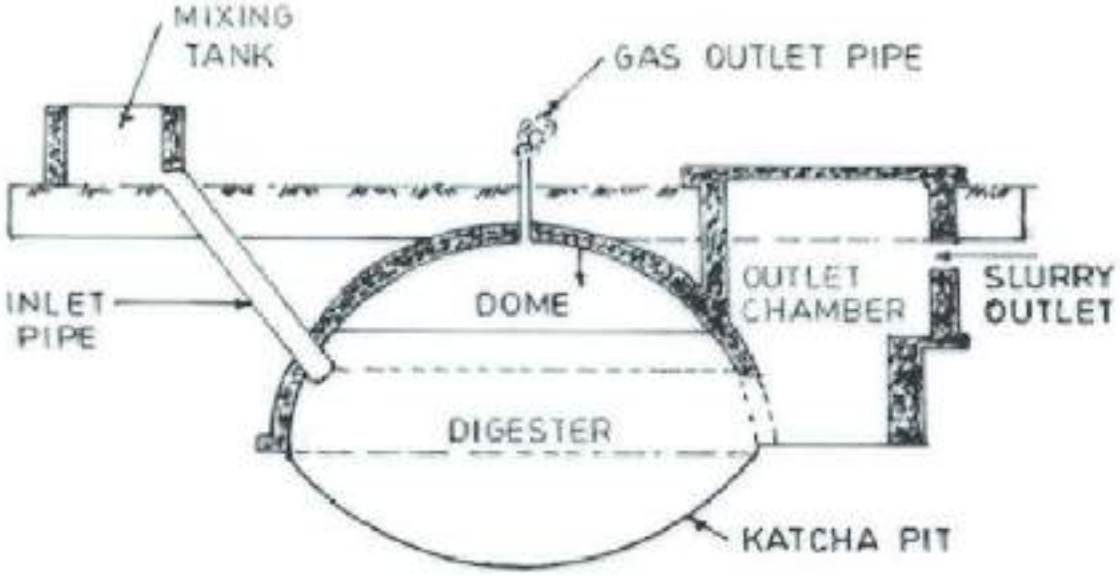


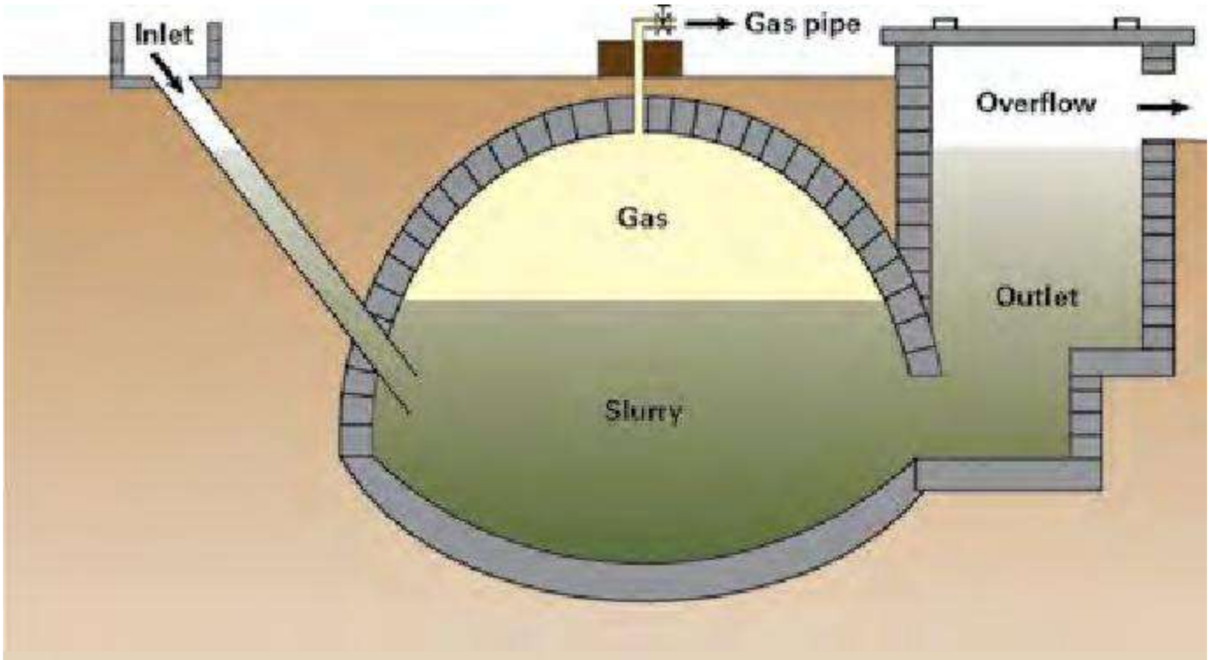
Floating dome biogas plant

Fixed dome digester

This digester, which was developed and is widely used in China, runs on a continuous batch basis. Accordingly, it could digest plant waste as well as human and animal wastes. It is usually built below ground level, hence it is easier to insulate in a cold climate.

The digester can be built from several materials, e.g. bricks, concrete; lime concrete and lime clay. This facilitates the introduction and use of local materials and manpower. The variable pressure inside the digester was found to cause no problems in China in the use of the gas.





Biogas Plant Models (India)

KVIC (Khadi and Village Industries Commission) design.

PRAD (Planning, Research and Action Division) design

Murugappa Chettiar Research Centre design.

Tamil Nadu Agricultural University dome type design

ASTRA (Application of Science and Technology to Rural Areas) design

Himachal Pradesh Capsule design

Kacha-Pucca model of Punjab Agricultural University

Plug-flow design

AFPRO (Action for Food Production) design

Roorkee design

Deen Bhandhu design

Fibreglass fixed dome design (Underground model)

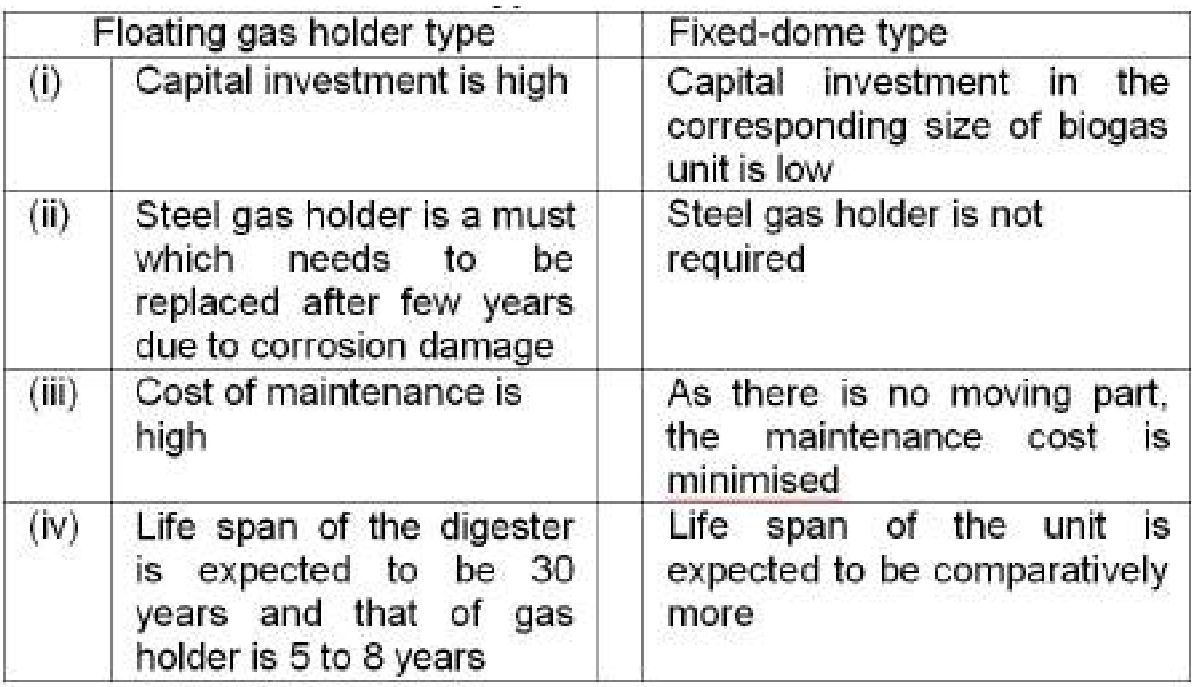
Mobile biogas plants

Plastic emulsion coated, heavily insulated, temperature controlled Switzerland biogas plants.

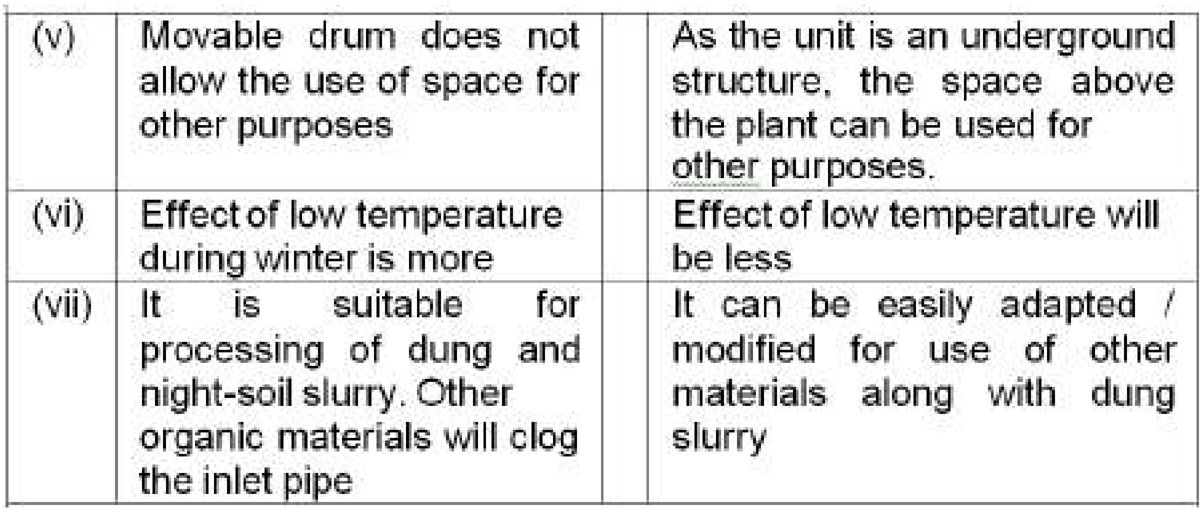
IARI (Indian Agricultural Research Institute) design

Ganesh Model

Ferro-cement Digester Biogas Plant

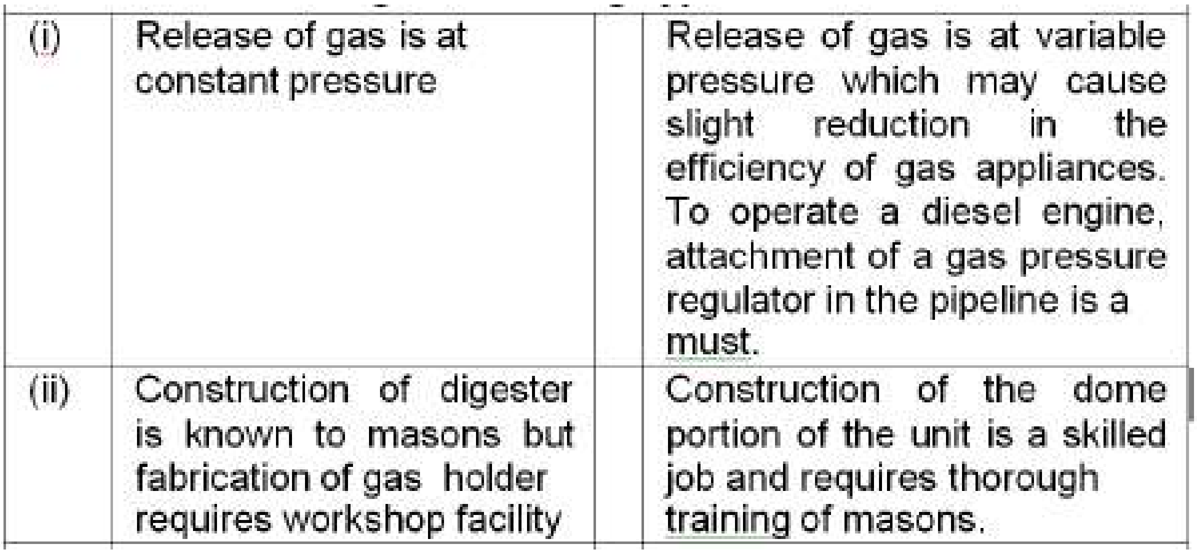


Floating gas holder type			Fixed-dome type
(i)	Capital investment is high		Capital investment in the corresponding size of biogas unit is low
(ii)	Steel gas holder is a must which needs to be replaced after few years due to corrosion damage		Steel gas holder is not required
(iii)	Cost of maintenance is high		As there is no moving part, the maintenance cost is minimised
(iv)	Life span of the digester is expected to be 30 years and that of gas holder is 5 to 8 years		Life span of the unit is expected to be comparatively more

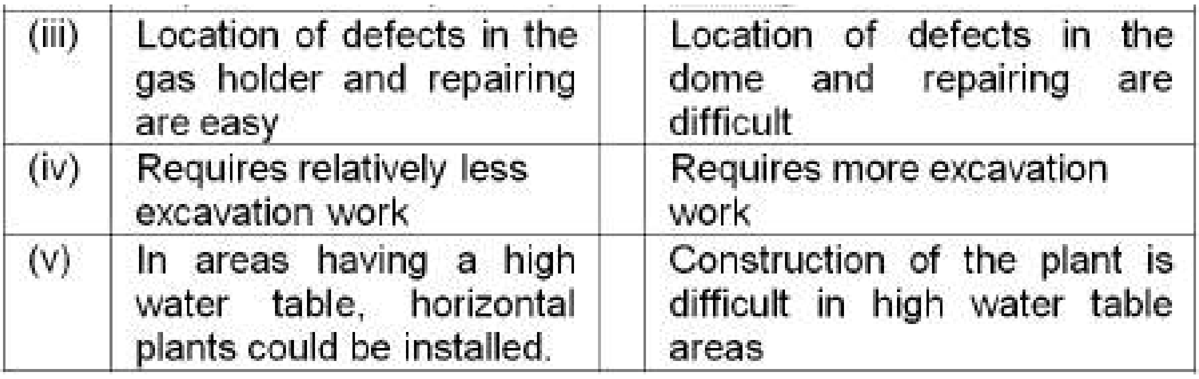


(v)	Movable drum does not allow the use of space for other purposes		As the unit is an underground structure, the space above the plant can be used for other purposes.
(vi)	Effect of low temperature during winter is more		Effect of low temperature will be less
(vii)	It is suitable for processing of dung and night-soil slurry. Other organic materials will clog the inlet pipe		It can be easily adapted / modified for use of other materials along with dung slurry

Merits of Floating Gas-Holding Type



(i)	Release of gas is at constant pressure		Release of gas is at variable pressure which may cause slight reduction in the efficiency of gas appliances. To operate a diesel engine, attachment of a gas pressure regulator in the pipeline is a must.
(ii)	Construction of digester is known to masons but fabrication of gas holder requires workshop facility		Construction of the dome portion of the unit is a skilled job and requires thorough training of masons.



(iii)	Location of defects in the gas holder and repairing are easy		Location of defects in the dome and repairing are difficult
(iv)	Requires relatively less excavation work		Requires more excavation work
(v)	In areas having a high water table, horizontal plants could be installed.		Construction of the plant is difficult in high water table areas

Site Selection for Biogas Plants

Distance

The distance between the plant and the site of gas consumption should be less in order to achieve economy in pumping of gas and minimizing gas leakage. For a plant of capacity $2m^3$, the optimum distance is 10 m.

Minimum gradient

For conveying the gas a minimum gradient of 1 % must be available for the line.

Open space

The sunlight should fall on the plant as temperature between 15 to 30° C is essential for gas generation at good rate.

Water table

The plant is normally constructed underground for ease of charging the feed and unloading slurry requires less labour. In such cases care should be taken to prevent the seepage of water and plant should not be constructed if the water table is more than 3m.

Seasonal runoff

Proper care has to be taken to prevent the interference of runoff water during the monsoon. Intercepting ditches or bunds may be constructed.

Distance from wells

The seepage of fermented slurry may pollute the well water. Hence a minimum of 15 m should be maintained from the wells.

Space requirements

Sufficient space must be available for day to day operation and maintenance. As a guideline 10 to 20 m^2 area is needed per m^3 of the gas.

Availability of water

Plenty of water must be available as the cowdung slurry with a solid concentration of 7 to 9 % is used.

Source of cow dung/ materials for biogas generation

The distance between the material for biogas generation and the gas plant (within 5 m) site should be minimum to economize the transport cost.

BiogasOperation & Maintenance

Operation and maintenance guidelines could be categorized as

(i) Daily routines, (ii) Weekly routines, (iii) Monthly routines and (iv) Half Yearly/Yearly routines.

Daily Routines/Maintenance

About 25 kg of cattle dung is required for generation of 1 m^3 gas per day. For higher capacities, the dung required for daily feeding is (25 x X) kg, where X is the capacity of the plant. The required quantity of dung along with equal quantity of water is fed into the mixing tank after plugging the inlet pipe.

The contents are thoroughly mixed. Materials like, straw, trash etc. should be removed. The slurry is then led into the digester by removing the plug put at the opening of the inlet.

After feeding, the inlet opening is again closed by the plug. The inlet tank is cleaned with water and the washing is drained out through the *hole provided at the lowest point* of the floor of the inlet tank Inorganic materials like sand, mud, *etc.* will get washed away while cleaning the mixing tank. In the case of KVIC model, the gas holder is given half rotation in clockwise and anticlockwise direction 2-3 times, immediately after feeding to break the scum on the surface of the digester slurry. This is to be repeated once more during the day, when the gas holder has submerged in the slurry. As far as possible, the main gate valve is opened only when gas is required. In any case, it should be made as a practice to close the gate valve at night, when no more gas is required. Next day the valve is opened when use of gas is to start. The air shutter's position is checked while starting the use of burner in the morning and is properly readjusted, if necessary. In the case of KVIC model, during the first month after commissioning the plant, it is likely that the outlet pipe is chocked by hard cattle dung that must have gone into the digester at the time of initial feeding. It may therefore be checked about the flow of the slurry from outlet pipe immediately after daily feeding. If there is any chocking, it may be cleared by inserting a long bamboo into the outlet pipe.

In winter, the rate of gas production would be low. As such it is better to use a little warm water for daily feeding so that slurry with lower temperature may not disturb the system inside the digester when daily feeding is done. One way is to make the slurry in the mixing tank in the morning and allow to get warm by direct solar energy. This slurry may be allowed inside the digester when no more sun rays fall on the slurry.

Weekly routines/Maintenance

The burners and lamps are to be cleaned. Particularly dirt, dust etc. if any at the ports and injector orifice of the burners are removed. Smooth gas flow must be ensured; similarly the nozzle of biogas lamp and the chimney are also cleaned. The water remover/water trap may be checked for any collection of water and the condensed water any be drained out, the plug is properly fitted again. If it is an automatic water remover, it may be checked for its proper functioning. In the case of fixed dome plants, a long bamboo may be inserted in the digester through the outlet gate and stirring is done to prevent accumulation of scum.In the case of KVIC model, the dry mat that must have been collected in the gap between the digester wall and the gas holder may be removed manually, so that smooth vertical motion of the gas holder is not disturbed.

Monthly Routine/Maintenance

Gate valve and gas pipe line be tested for leakage and rectification is done if found necessary. Gas taps/gas cock may need lubrication which may be done.Ventury and mantles of gas lamps may be checked and replaced if necessary. If the manure pit by the side of the gas plant is full, the outlet slurry may be diverted to the next pit.

Half Yearly / yearly Routines/Maintenance

Leakage and corrective steps are taken where necessary. Particularly the flexible pipe connected the gas outlet and the main pipe line (KVIC biogas plant) may be checked for leakage and replaced if found brittle.

In the case of KVIC model, outer surface of the mild steel gas holder is prone to corrosion more than the inner surface.

For protecting the gas holder from corrosion, outer surface need to be painted once in a year. Sometimes, it may be necessary to paint in about 6 months, if the earlier painting has not been proper and the atmosphere is humid. It is not necessary to take out the gas holder from its position. When the gas holder if full with gas, the main gate valve may be closed, entire outer surface visible above slurry level is thoroughly cleaned with water.

Wire brush may be used for cleaning the rusted portion if any. Black enamel paint is applied over the entire surface. The paint may be allowed to dry for one day and then the gas should be allowed to pass in the pipe line for routine use. Worn out accessories are to be repaired or replaced. The manure from the pits which are full is removed for manuring purpose and the pits are kept ready for further use.

UNIT II

BIO ENERGY

Biomass Sources

1. Plant materials
a) Starches/sugars/oils
b) Lignocellulose
2. Algae
3. Organic wastes
a) Agricultural (crop and animal waste)
b) Urban (food and wood waste)

Utilization of Biogas

Biogas is a valuable renewable energy and also a secondary energy carrier produced from biodegradable organic materials via anaerobic digestion. It can be used as a fuel or as starting material for the production ofchemicals, hydrogen and/or synthesis gas etc. The main constituents of biogas are methane (CH4) and carbon dioxide (CO2), with various quantities of contaminants, such as ammonia (NH3), water vapour (H2O), hydrogen sulfide (H2S), methyl siloxanes, nitrogen (N2), oxygen (O2), halogenated volatile organic compounds (VOCs), carbon monoxide(CO) and hydrocarbons. These contaminants presence and quantities depend largely on the biogas source, which could be anaerobic digestion of many substrates and landfill decompositions. The removal of these contaminants especially H2S and CO2 will significantly improve the quality of the biogas for its further uses. In parallel, biogas upgrading market is facing challenges in term of operating costs and energy consumption. The selection of appropriate technology depends on the specific biogas requirements, site specific, local circumstances and is case sensitive. This paper reviews the present state-of-thartofbiogasleaningandupgradingtechnologies, includingits composition, upgrading efficiency, methane recovery and loss.

In addition, biogas production, utilization and the corresponding requirements on gas quality for grid injection and vehicle usage are investigated. Based on the results of comparisons of various technologies, recommendations are made on further research on the appropriate low cost technologies, especially using solid waste as low cost materials for biogas purification and upgrading.

Bioenergy is renewable energy generated from biological source materials, and includes electricity, transportation fuels and heating. Source materials are varied types of biomass, including food crops such as corn and sugarcane, non-edible lignocellulosic materials such as agricultural and forestry waste and dedicated crops, and municipal and livestock wastes. Fuels produced from the conversion of these materials include biodiesel and bioethanol liquid biofuels, and biogases. Some solid fuels can be used following relatively little processing, demonstrated by the direct combustion of densified wood chips. These varied fuels can be utilized alone or in conjunction with conventional fossil fuels, as in blends of bioethanol with gasoline, and the co-firing of wood and coal. Furthermore, fuels can be applied towards multiple end uses, including from within shared facilities which can co-generate electricity and heat. In these ways, bioenergy allows for diverse end uses from a variety of biologically based sources and fuel types.

Biogas

Biogas serves as a suitable alternate fuel for satisfying the energy needs of human society. It can be used for production of power, for cooking and lighting.

It is formed by the bacterial degradation of biomass under anaerobic condition (airtight digesters). Biogas mainly contains methane (50-70%), carbon dioxide and trace amount of water, sulfur and hydrogen sulphide.

Biogas generation

The biogas generated by anaerobic digestion of organic waste (animal waste, plant residue, crops) in biogas plant, mainly involve three steps: hydrolysis, acid formation and gas production.

Hydrolysis

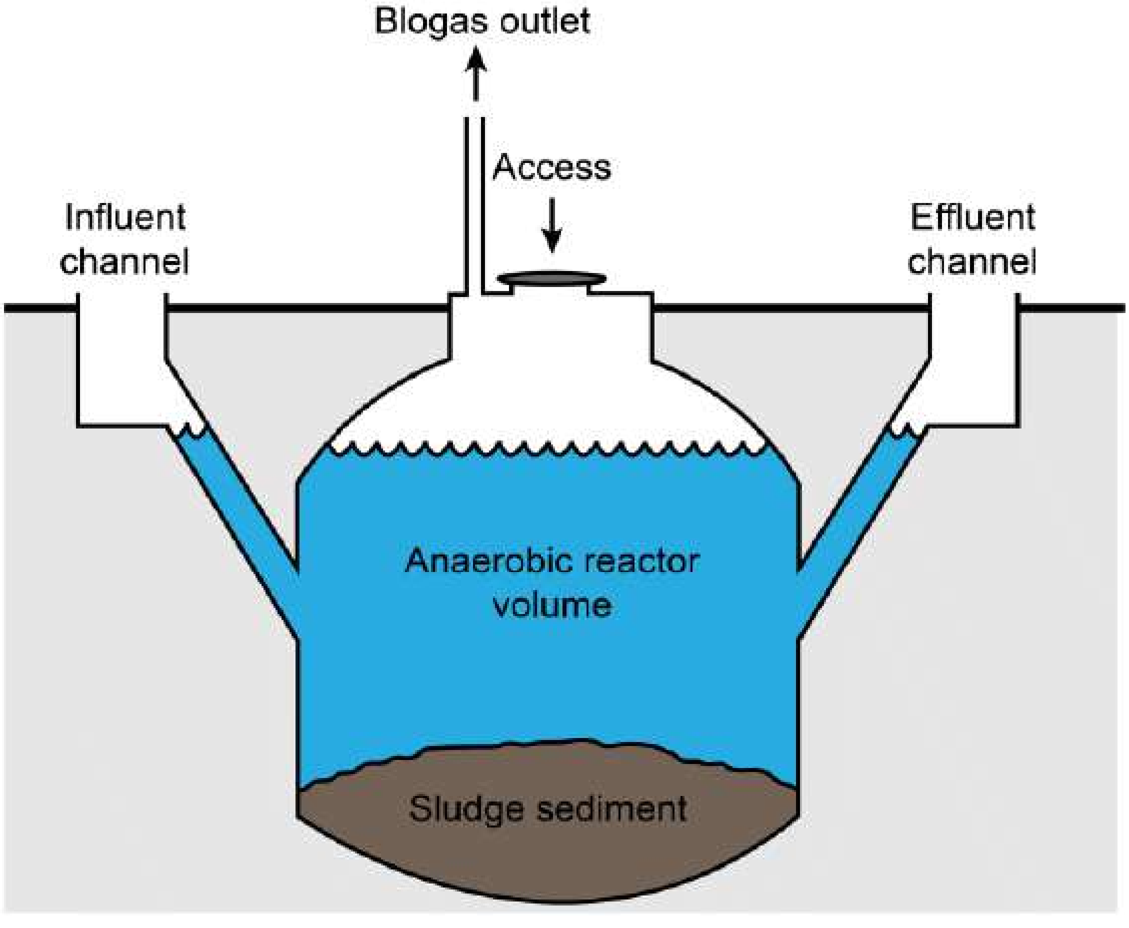
In this step, macromolecule like fats, proteins, carbohydrates are broken down through hydrolysis into fatty acids, amino acids and sugars respectively.

Acid formation

in this step, fatty acids, amino acids and sugars are fermented by acid producing bacteria under anaerobic condition into acetic acid, carbon dioxide and hydrogen.

Gas production

In this step, methanogenic bacteria produce methane either by fermenting acetic acid to form methane and carbon dioxide or by reduction of carbon dioxide into methane.



Advantage of biogas

i) Produce organic waste

ii) Burn without smoke iii) Renewable iv) Help to reduce waste.

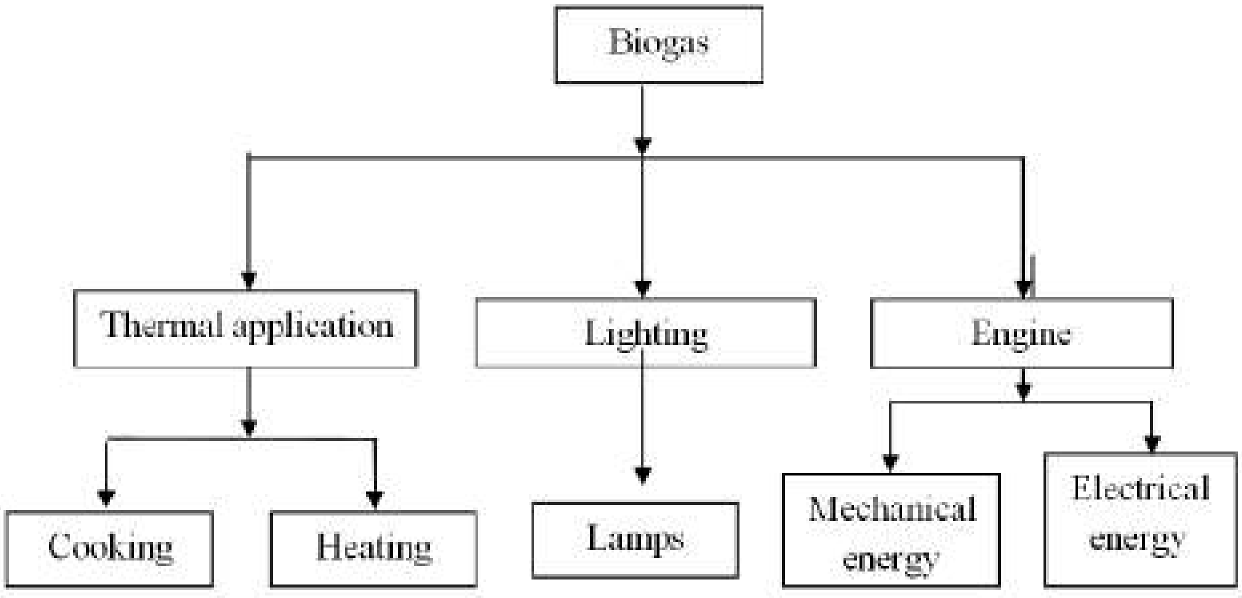
Disadvantage of biogas

i) Methane is health hazardous. ii) Not efficient like fossil fuel.

Bio gas generated through a process of anaerobic digestion of Bio Mass. Bio Mass is organic matter produced by plants, both terrestrial (those grown on land) and aquatic (those grown in water) and their derivatives. It includes forest crops and residues, crops grown especially for their energy content on “energy farms” and animal manure.

Biogas is a clean and efficient fuel. The chief constituent of biogas is methane (65%). It is a mixture of following gases.

Applications of biogas



Heating applications

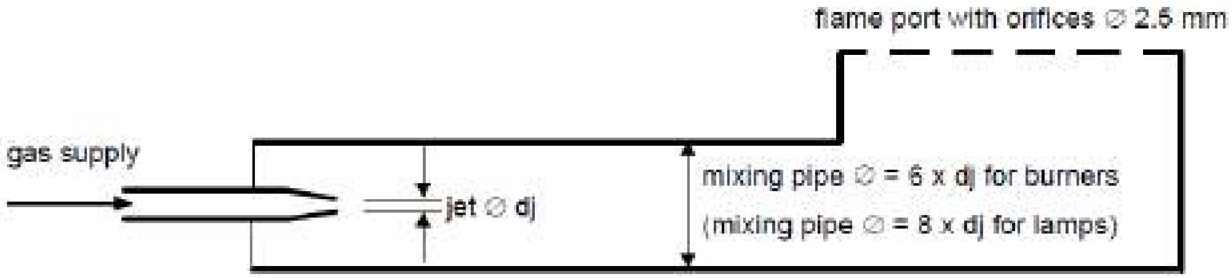
The most efficient use of biogas is cooking and other direct heating applications. Biogas burners normally operate at gas pressure of 75 to 90 mm water column. Brightness and combustibility of gas can be controlled by regulating gas pressure and air-fuel ratio which is generally maintained as 10:1. The calorific value of biogas is directly proportional to the amount of methane content available in biogas.

The Biogas burns with blue flame and without any soot and odour which is considered to be one of the major advantages compared to traditional cooking fuel like firewood and cow dung cake. The major components of the gas are methane (CH4) and carbon dioxide (CO2). Methane is a flammable, colour less, odour less and tasteless gas. Combustion of methane releases heat energy during biogas burning. For the liquefaction of biogas the required temperature and pressure are -82.1°C and 47.4 kg/m^2, respectively.

Cooking

The major **common application** of biogas is cooking. A 2 m^3 of biogas plant will supply fuel gas for satisfying daily cooking of a family of 3 to 4 members.

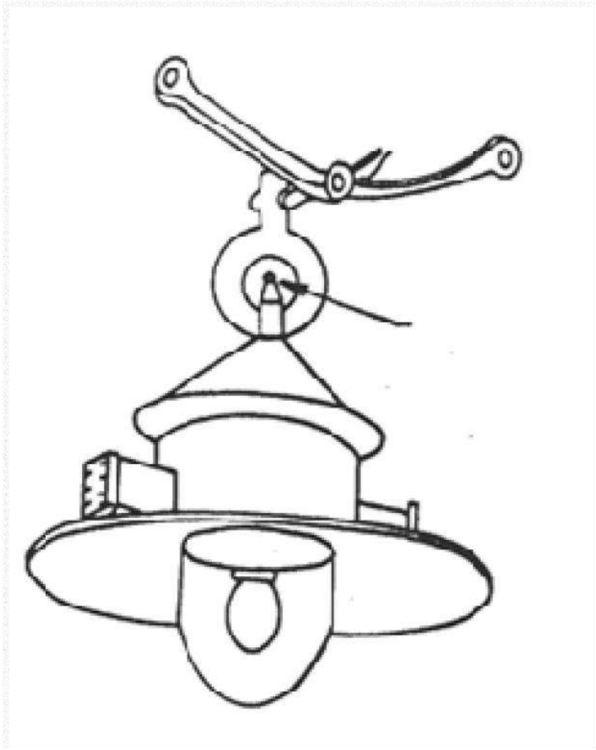
Stoves specifically designed for biogas are available which make the best use of the fuel – a much higher fuel: air ratio is required with biogas burners compared to butane burners (1:6 by vol. compared to 1:30)[5]. These are available from a number of manufacturers for between US $15-$30 (e.g. Rupak Enterprises, India) [9] or can be made more cheaply locally (see Case Study II). Alternatively simple modifications can be made to butane/propane stoves (by expanding the gas jet cross-section by 2-4 times or modifying fuel: air ratio by adjustment if possible) to obtain the desired compact and slightly blueish flame [5]. Figure 1 shows the relative ideal diameters of the biogas jet and the mixing pipe. Figure 2 shows a biogas stove in use



Lighting

In biogas lamp when gas is burnt, mantle of the lamp glows which causes lighting. Mantle in biogas lamp is similar to one used in a Coleman or propane lamp. Mantle is normally made of Ramie fibre and is coated with thorium nitrate solution. Nozzle in the biogas lamp is of the size of a needle point having 0.5 to 0.7 mm diameter. The other end of the nozzle is connected to gas supply hose which is linked to a biogas plant. Biogas emerges out from the nozzle at very high temperature forming low pressure area around it and hence air is drawn into the mixing chamber to freely mix with it.

Lighting can be provided by means of a gas mantle, or by generating electricity. Biogas mantle lamps consume 2-3 cft per hour having illumination capacity equivalent to 40 W electric bulbs at 220 volts. This application is predominant in rural and unelectrified areas.



Biogas can be used in gas lamps to provide lighting which can be used, for example, to light the toilets. With an efficient biogas lamp, a lighting intensity comparable to that of an electric bulb of 25-75W can be produced. Biogas lamps can be purchased from a number of manufacturers (in China, India and Brazil) from around US $6 [10]. References to a popular Brazilian design – the 'Jackwall' lamp (c. USD $10) have been made in a number of internet articles however suppliers/technical information on this particular model cannot be found. Biogas mantle lamps such as the one shown in Figure 3 (source: Sustainable Sanitation (Flickr), Kabul) are relatively common. Alternatively normal gas lamps can be modified for efficient biogas use (however they will never be as fuel efficient as kerosene ones). Again the gas jet should be widened so that the diameter of the jet is approximately 1/6 that of the mixing pipe (see Figure 1). The flame should be adjusted to be the same size as the mantle, with a uniform brightness and a steady sputtering murmur.

Electricity generation

For the simplest, smallest scale electricity generation it is possible to run adapted diesel engines on a mixture of biogas and diesel. GTZ suggest that a largely unmodified diesel engine can be used with only the addition of a gas/air mixing chamber (50%-100% of the cylinder size) situated on the air intake. Engines can run without stuttering (stuttering signifies a too high biogas: diesel ratio) on a biogas: diesel ratio of up to 4:1 (80% biogas, 20% diesel). This can be achieved simply by tuning down the amount of diesel entering the engine. According to GTZ 1.5m3 of biogas with 0.14l of diesel can produce 1kWh of electricity.

Although large scale electricity generation in developed countries (especially Germany) is common, it is still relatively rare in developing countries due to the required quality (and therefore processing) of the gas (levels of CO2,
H2S and water vapour need to be reduced). A publication by GTZ ('Engines for Biogas') describes in detail suitable engine modifications and design (see Further Reading).

Engine applications

Biogas can be used as a fuel in stationary and mobile engines, to supply motive power, pump water, drive machinery (e.g., threshers, grinders) or generate electricity. It can be used to operate four stroke diesel and spark ignition engines. Electricity generation using biogas is a commercially available and proven technology. Typical installations use spark-ignited propane engines that have been modified to operate on biogas. Biogas-fueled engines could also be used for other on-farm applications. As discussed below, diesel or gasoline engines can be modified to use biogas.

IC engines (typically used for electricity generation) can be converted to burn treated biogas by modifying carburetion to accommodate the lower volumetric heating value of the biogas into the engine and by adjusting the timing on the spark to accommodate the slower flame velocity of biogas ignition systems.
When biogas is used to fuel such engines, it may be necessary to reduce the hydrogen sulphide content if it is more than 2 percent otherwise the presence will lead to corrosion of engine parts. In terms of electricity production, small internal combustion engines with generator can be used to produce electricity in the rural areas with clustered dwellings thus promoting decentralized form of electricity avoiding grid losses.

Use of biogas as vehicular fuel

Biogas is suitable as a fuel for most purposes, without processing. If it is to be used to power vehicles, however, the presence of CO2 is unsatisfactory, for a number of reasons. It lowers the power output from the engine, takes up space in the storage cylinders (thereby reducing the range of the vehicle), and it can cause problems of freezing at valves and metering points, where the compressed gas expands, during running, refueling, as well as in the compression and storage procedure.

All, or most, of the CO2 must therefore be removed from the raw biogas, to prepare it for use as fuel for vehicles, in addition to the compression of the gas into high-pressure cylinders, carried by the vehicle.

Spark Ignition engines

Spark ignition (SI) engines can run completely on biogas, however, the engines are required to be started on petrol at the beginning.

The conversion of SI engine for operation on biogas includes provisions for the entry of biogas, throttling of intake air and advancing the ignition timing. Biogas can be admitted to a stationary SI engine through the intake manifold and an air flow control value can be provided on the air cleaner pipe connecting the air cleaner and carburetor for throttling of intake air.

Compression Ignition engines

Compression Ignition engine can operate on dual fuel and the necessary engine modifications include provision for the entry of biogas with intake air, advancing the injection timing and provision of a system to reduce diesel supply. The entry of biogas and mixing of gas with intake air can be achieved by providing a mixing chamber below the air cleaner which facilitates through mixing of biogas with air before entering into the cylinder.

Bottling of biogas

Methane gas is unlike commercially available bottled butane or propanegas,liquefiesatabout1.75MN/m^2(18kgf/cm^2). pressureofabout34.5MN/m^2(350kgf/cm^2)isrequiredfor liquefaction of methane. BiogasmustbecleanedofallH_2Sasthiswould corrode the storage bottles. It should also be cleaned of CO_2, as there is no advantage in compressing this. About 20 per cent of the energy available in the methane is required to compress the gas. Typical steel storage bottle would be about 1.6 m long x 0.27 m in diameter; capacity 54 litres, weight 63 kg. It would hold 12 m^3 of cleaned methane gas which is the equivalent to 18.5 m^3 of biogas. Assuming that the biogas consists of 65 per cent methane and the gas pressure used is about 20 MN/m^2 (210 kgf/cm^2), this is equivalent to about 16 litres of petrol or 14.5 litres of kerosene. Considering the cost for cleaning the gas, compressing it, purchasing the special high pressure storage bottle and transporting these heavy bottles, it is obvious that in most cases this proposition is neither economic nor practical.

Bio-digested Slurry

Biogas plant (BGP) with anaerobic digestion providing a facility to generate manure (Biogas spent slurry) and energy generation. The digested biogas slurry (DBGS) is rich in macro and micro nutrients that provide essential plant nutrients for longer period. Biogas slurry may be considered as a good quality organic fertilizer for sustainable agriculture. Biogas slurry provides huge nutrient potential for vegetative and reproductive growth of field crops with long term sustainability. By applying the digested biogas slurry (DBGS) in the field for long term basis help in reducing fertilizer demand and provide an eco-friendly way of maintaining productivity and soil health. In this study we are summarizing nutrient potential of digested biogas slurry (DBGS) and relation with synthetic fertilizers in India, as a potential source.

Biogas slurry is a by-product of anaerobic digestion that produced from biogas plant and also produces biogas (combustible methane gas) that is used for cooking, lighting and running engines. Bioslurry can be used to fertilize crops directly or added with other organic materials and synthetic fertilizers. Bioslurry is a digested source of animal waste and if urine (animals) is added, more nitrogen is added to the bioslurry which can speed up the compost-making process in short period of time. This improves the carbon/nitrogen (C/N) ratio in the slurry that provides easily nutrient availability to plants and soil biota.

The biogas slurry has 93% water and 7% of dry matter, of which 4.5% is organic matter and 2.5% inorganic matter. The digested biogas slurry also contains phosphorus, potassium, zinc, iron, manganese and copper, out of which many depleted from soil due to intensive agricultural practices. Bioslurry can also be used to build up health fertile soil for crop production. Bioslurry contains easily-available plant nutrients and it contains higher amounts of nutrients and micronutrients than composted manure and FYM (Ishikawa et al. 2006). The effects of bioslurry application are comparable to the effects of the application of synthetic fertilizers. Hence, digested bioslurry can be a precious alternative to synthetic fertilizers. Biogas slurry is considered a good source of organic fertilizer as it contains considerable amounts of both macro (N, P, K) and micronutrients (Zn, Mn, B) that are necessary for plant growth (Alam, 2006). Use of biogas slurry is providing a sustainable way for agriculture, environment and farming communities.

Synthetic fertilizers can increase the soil's nutrients more than organic fertilizers. But synthetic fertilizers are able to provide only particular nutrients to the crops. Farmers use synthetic fertilizers to increase crop production immediately that on other hand intense and continuous use of such synthetic fertilizers creates crops that are susceptible to insect attacks, microbial pathogens and intrusive weeds. If only synthetic fertilizers are added to the soil, without organic manure (slurry, FYM and compost) decreases soil productivity and if only organic manure is added, decrease the desired crop yields (Liu et al. 2009). Most of time, optimum crop yield and soil fertility levels can be achieved through the combination of synthetic and organic fertilizers. Synthetic fertilizers are expensive and most small-scale farmers cannot afford them for a long duration. The high costs involved make it essential for most of developing and African countries to find an alternative to synthetic fertilizers (Dahiya et al. 1985). Furthermore, often the bioslurry combined with synthetic fertilizers shows better yields than bioslurry utilization on its own (Groot et al. 2013).

The use of biogas slurry reduces costs, as synthetic fertilizers are no longer necessary and crop production increases. Due to the results of the different studies and taking into account environmental effects and costs of synthetic fertilizers, using around 10 to 15 t/ha of biogas slurry is suggested, starting fertilizing after ploughing and 21 to 28 days before planting. Once the sprouts are above ground biogas slurry application should be done solely by spreading it onto the roots of the plant at noon while mixing it with the soil (Karki, 2001).

However, the economic value of organic fertilizer to a farmer is the value of increase in crop yields and/or crop quality that is derived from its use. The cost benefit ratio will determine the economic aspects of its use (Alam, 2006).

One cubic meter slurry contains 0.16 – 1.05 Kg N which is equivalent to 0.35-2.5 Kg urea (Vinh, 2010).

The nitrogen content of slurry is 1.5% (1.5% N, 1.1% P and 1% K).

From 730 MT dung, 76.8 MT slurry produced per year (only for bovine dung).

In 76.8 MT slurry, nitrogen content is 1.15 MT nitrogen.

1 kg Nitrogen is equivalent to 2.2 kg Urea fertilizer (Urea contains 46 % N).

Cost of urea is Rs. 276/50 kg bag
So cost of 1.15 × 109 kg N will be 13.74×109 INR.

As per above estimation, we can say that 76.8 MT slurry effectively reduce import bill by 13.74 billion INR. Mineral fertilizers alone cannot correct all the nutrients deficiency in agricultural soils. The prices of the imported fertilizers will continue to increase in from last few decades. Therefore, transformation of all native organic resources and recycling them into soil fertilization program should be undertaken early as much possible. The use of biogas slurry can reduce the application of synthetic fertilizers to a great extent. It is possible to reduce the use of the synthetic fertilizers up to 15-20%.

Biogas slurry may be considered as a good quality organic fertilizer in sustainable agriculture for maintaining the quality of produce. Biogas slurry has potential to provide a considerable amount of both macro and micro nutrients besides appreciable quantities of organic matter. Along the richness in nutrients it also has very low amount of heavy metals as compared to synthetic fertilizers. Biogas slurry (Dry-DBGS & Wet-DBGS) is environmental friendly, has no toxic or harmful effects and can easily reduce the use of chemical fertilizers up to 15-25%.

Biogas slurry has significant potential to improve the physical and biological quality of soil (improvement in soil structure, improvement in water holding capacity, cation exchange capacity, lesser soil erosion and provision of nutrients to soil micro-flora including nitrogen fixing and phosphorous solubilizing organisms) besides providing both macro and micro-nutrients to crops. Yield increases due to biogas slurry application, have also reported for many crops including field crops, tobacco, castor, peas, mustard, onion, cabbage, banana, chillies, pearl millet and sugarcane. A combination of biogas slurry (Dry-DBGS & Wet-DBGS) and synthetic fertilizer enhanced carbon nitrogen transformation with substantive effect on crop yield. Finally, we come out with conclusion that biogas slurry provide a beneficial way for farmer's community, reduce fertilizer burden on economy of country and improve sustainability of field.

Biodigested Slurry (BDS) is the by-product obtained from the biogas plant after the digestion of the dung and generation of the fuel gas. The BDS is very good manure similar to FYM available in the farm but it becomes very much different after the digestion process. The nutrient contents viz.

NPK get enriched in the BDS compared to the FYM. The average macro-nutrient content of some commonly available organic manures are given below.

Uses of biodigested slurry

The slurry after the digestion will be washed out of the digester which is rich in various plant nutrients such as nitrogen, phosphorous and potash. Well-fermented biogas slurry improves the physical, chemical and biological properties of the soil resulting qualitative as well as quantitative yield of food crops. Slurry from the biogas plant is more than a soil conditioner, which builds good soil texture, provides and releases plant nutrients.

Since there are no more parasites and pathogens in the slurry, it is highly recommended for use in farming. The economic value of the slurry shows that investment can be gained back in three to four year's time if slurry is properly used. The cow dung slurry after digestioninside the digester comes out with following characteristics and has following advantages:

When fully digested, effluent is odourless and does not attract insects or flies in the open condition. The effluent repels termites whereas raw dung attracts them and they can harm plants fertilized with farmyard manure (FYM).Effluent used as fertilizer reduces weed growth with about 50%. When FYM is used the undigested weed seeds cause an increased weed growth. It has a greater fertilizing value than FYM or fresh dung. The form in whichnitrogen available can be easily assimilated by the crops.

Advantages

Contains 1.5% nitrogen
Free of flies, mosquitoes
No smell
Used as Farm Yard Manure by adding necessary rock phosphate.

Comparison of nutrient content of some commonly available organic manures and biodigested slurry

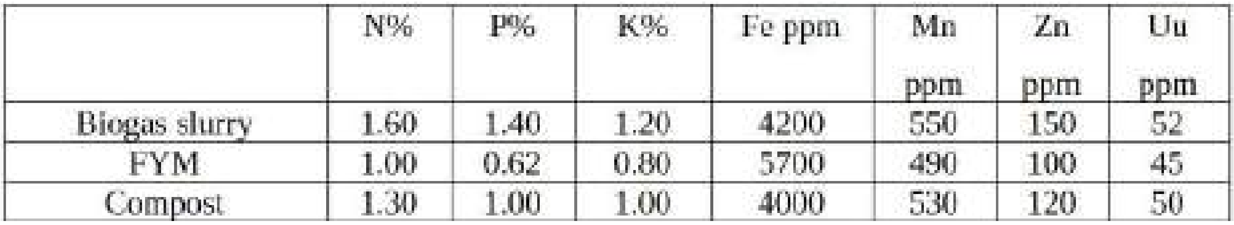
SL.No.	Manure	N(%)	P2O5 (%)	K2O(%)
1	BDS	1.5 - 2.5	1.0 - 1.5	0.8 - 1.2
2	Fresh cattle dung	0.3 – 0.4	0.1- 0.2	0.1 – 0.3
3	Farmyard manure	0.4 – 1.5	0.3 - 0.9	0.3 - 1.9
4	Compost	0.5 – 1.5	0.3 - 0.9	0.8 - 1.2

Like compost and FYM, BDS improves soil fertility, soil porosity and water holding capacity. It supports bacterial growth in soil that facilitates release of vital nutrients, which contribute to increased crop productivity. Besides this, BDS becomes free of weed seeds, odour etc and so it is a highly valuable organic manure than the FYM.

The digested slurry is fed through the channel, flowing over a layerofgreenordry leaves and filtered in the bed. The water from the slurry filters down which can be reused for preparing fresh dung slurry. The semi-solid slurry can be transported easily as it was in the consistency of fresh dung and used for top dressing of crops like sugarcane and potato.

Biodigested slurry is also being used for fish culture, which acts as a supplementary feed. On an average, 15-25 litre of wet slurry can be applied per day in a 1200 sq pond. Slurry mixed with oil cake or rice-bran in the 2:1 ratio increases the fish production remarkably
In general organic manures about 10 t / ha, in the form of FYM or compost or biodigested slurry is recommended to be applied once in three years to maintain the organic content of soil, besides providing nitrogen, phosphorous and potassium in the form of organic fertilizers to the crop.

Nutrient contents of organic manures



	N%	P%	K%	Fe ppm	Mn ppm	Zn ppm	Uu ppm
Biogas slurry	1.60	1.40	1.20	4200	550	150	52
FYM	1.00	0.62	0.80	5700	490	100	45
Compost	1.30	1.00	1.00	4000	530	120	50

Bioslurry is a good fertilizer for crops and improves the soil fertility, soil structure and yields of crops. It is often even better than regular Farmyard Manure (FYM) and may also reduce the use of chemical fertilizers. With the right rate of 10 to 20 tons/ha in irrigated areas and 5 tons/ha in dry farming, crops can show significant increase in yields. Indeed, bioslurry increases crop revenues by 25 percent on average.

Bioslurry is used to improve soil fertility, soil structure, and crop productivity, and it can be an excellent fertilizer. However, not many farmers are familiar with the advantages of bioslurry. This article brings together the main findings of available research on bioslurry as well as information from the field in Hivos' and SNV's biodigester programmes.

Enrichment

The nutrient values of biodigested slurry can be increased considerably by means of enrichment, thereby reducing the quantum of slurry required for application to get the desired level of nutrient. Otherwise, we need to apply large amounts of dried slurry to obtain higher crop yields. An effective method of treating such manure is to enrich them with fertilizer nitrogen and with phosphate fertilizers to obtain concentrated organic mineral fertilizer which could be applied in comparatively smaller quantity.

Enrichment by impregnation

The enrichment can be done by taking 11 kg of urea and 31 kg of super phosphate and dissolving them in about 15 litres of water. This solution is adsorbed in 48 kg of dry low grade manure and mixed thoroughly and spread out in the shade to dry. The enriched manure would then contain 5 percent P2O5 in addition to the original contents. Such impregnated manures have been found to give high response in field experiments.

Enrichment by pelletization

Enrichment of biodigested slurry is also done by pelletization with rock phosphate and coir-pith.A pelletizer has been developed for densification of biodigested slurry into granules or pellets.The pelletizer consists of two major components, viz. pellets extruder and gyratory shaker.

The biodigested slurry is enriched with 50 g of rock phosphate and 100 g of powdered coir waste per kg of slurry, with addition of 70 - 75 percent moisture. Enriched biodigested slurry of optimum consistency is fed into the hopper of the pellet extruder and the feed material is extruded by helical screw through spout and made into thick noodles. The noodles are cut into small equal pieces and made into spherical pellets in a gyratory shaker. Addition of enriched pellets about 2 tonnes per hectare to many crops like ragi, sorghum, maize has been 'found to increase the yield.

Biocatalysis

Biocatalysis refers to the use of living (biological) systems or their parts to speed up (catalyze) chemical reactions. In biocatalytic processes, natural catalysts, such as enzymes, perform chemical transformations on organic compounds. Both enzymes that have been more or less isolated and enzymes still residing inside living cells are employed for this task.

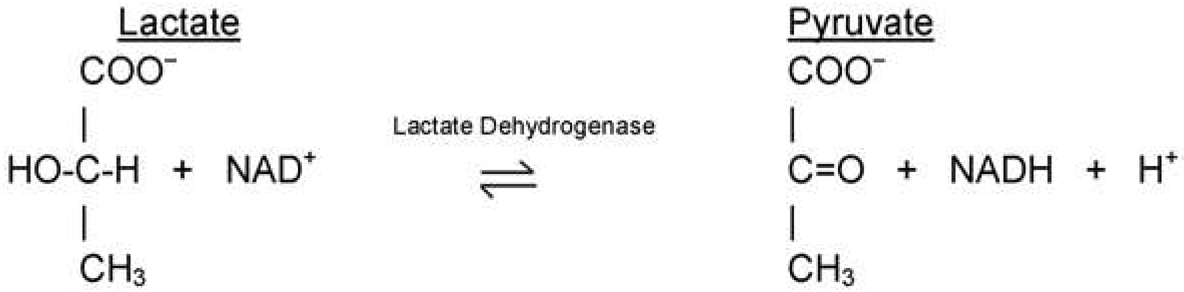
A catalyst is a substance which alters to promote the reaction, and a substance especially an enzyme that initiates or modifies the rate of a chemical reaction in a living body is termed as biocatalyst. They are enzymes or microbes that initiate or accelerate chemical reactions.

Chemical transformations carried out by every living organism are enabled by thousands of proteins (enzymes) which have catalytic activity for conversion of a particular set of substrates to specific products. Biocatalysis is the general term for the transformation of natural and non-natural compounds by enzymes. Because of this, the term biocatalysis is also referred to the application of enzymes in chemistry(Bommarius and Riebel, 2004).Over 3,000 enzymes have so far been identified, and this number will greatly increase thanks to the contribution of genomic and proteomic research. As catalysts, enzymes have remarkable specificities and sometimes phenomenal rate accelerations. A wide array of complex molecules is accepted by enzymes, including synthetic molecules with structures very different forms the substrates found in nature. Biocatalysts are also endowed with selectivity, catalyzing reactions with unique chiral (stereo-) and positional (regio-) selectivities. The basis for the action of all enzymes as chemo-, regioandstereospecific catalysts lays in their structure. Out of 20 amino acid, 19 of them areenantiopureL-amino acids providing an asymmetric microenvironment for substrate binding and subsequent chemical transformation in the enzyme active site .These features make biocatalysis attractive as a complementary tool for transformations both in organic chemistry and in industry (Liese et al., 2006).

Enzymes

Enzymesarechemicalsubstanceswhich are mostly proteins.Enzymes catalyze nearly all the biochemical reactions in the living cells. They have unique three dimensional shapes that fits the shape of reactants. Enzymes are typically derived from plants, micro-organisms (yeast, bacteria or fungi) or animal tissue (e.g. protease from pancreas.

Enzymes are biological catalysts (also known as biocatalysts) that speed up biochemical reactions in living organisms, and which can be extracted from cells and then used to catalyze a wide range of commercially important processes. This chapter covers the basic principles of enzymology, such as classification, structure, kinetics and inhibition, and also provides an overview of industrial applications. In addition, techniques for the purification of enzymes are discussed. Enzymes are potent catalysts, Enzymes are specific catalysts.



$$\begin{array}{l}\mathrm{COO^-}\\ |\\ \mathrm{HO\text{-}C\text{-}H}\\ |\\ \mathrm{CH_3}\end{array} + \mathrm{NAD^+} \xrightleftharpoons{\text{Lactate Dehydrogenase}} \begin{array}{l}\mathrm{COO^-}\\ |\\ \mathrm{C{=}O}\\ |\\ \mathrm{CH_3}\end{array} + \mathrm{NADH} + \mathrm{H^+}$$

Commercial sources of enzymes are obtained from three primary sources, i.e. animal tissue, plants and microbes. These naturally occurring enzymes are quite often not readily available in sufficient quantities for food applications or industrial use. However, by isolating microbial strains that produce the desired enzyme and optimizing the conditions for growth, commercial quantities can be obtained.

This artificial method of producing enzyme was earlier known as Fermentation. Today, this fermentation process is carried out in a container vessel. Once fermentation is completed, the microorganisms are destroyed; the enzymes are isolated, and further processed for commercial use. Enzyme manufacturers produce enzymes in accordance with all applicable governmental regulations, including the appropriate federal agencies such as FDA (Food & Drug Administration, Chemical industries, research laboratories.

Types of biocatalysts

Microbes: e.g. yeast, and other anaerobic bacterias

Lipases: These are the most widely used class of enzymes in organic synthesis; they are preferred widely because of their better stability as compared to others.

Proteases: Enzymes which break down proteins.

Cellulases: Enzymes which break down cellulose.

Amylases: which break down starch into simple sugars.

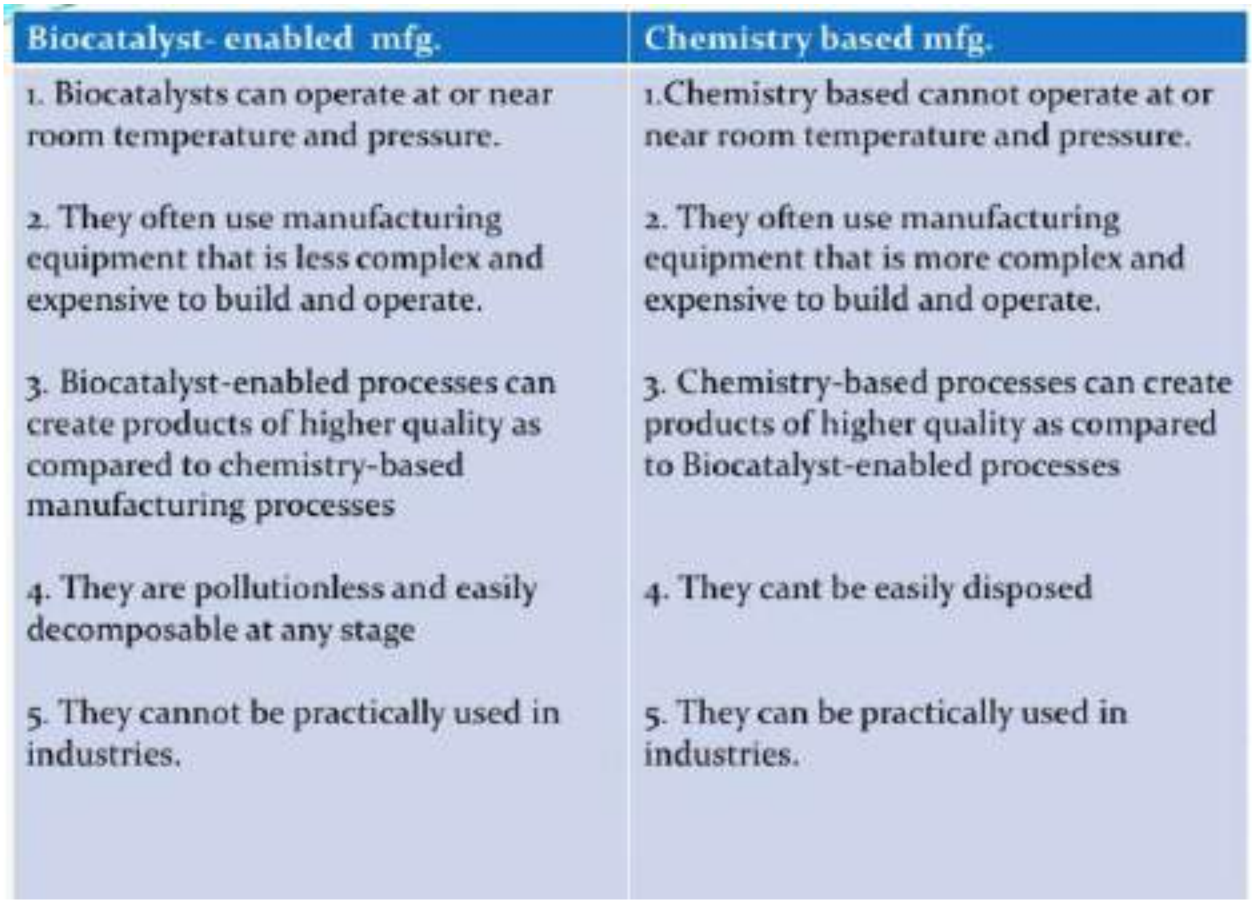
Enzymes speed up chemical reactions in a natural way. As they are not alive, they remain as inert mass of proteins. Enzymes work by weakening bonds which lowers activation energy.

Biocatalysts are used in Food industries for processing.

It is used in diagnostic tests. Biocatalysts are the most important aspect in molecular biology (DNA replication, cloning). For e.g. Polymerases (to polymerize) Restrictases (to cut the DNA strands) DNA ligases (to bind the DNA strands).

Demerits of Biocatalysts

Enzymes require narrow operation parameters. Enzymes display their highest catalytic activity in water. Enzymes may cause allergies.



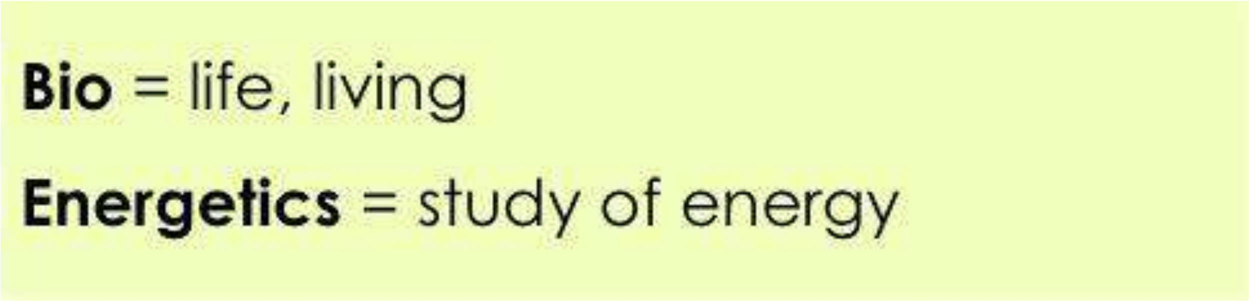
Biocatalyst- enabled mfg.	Chemistry based mfg.
1. Biocatalysts can operate at or near room temperature and pressure.	1.Chemistry based cannot operate at or near room temperature and pressure.
2. They often use manufacturing equipment that is less complex and expensive to build and operate.	2. They often use manufacturing equipment that is more complex and expensive to build and operate.
3. Biocatalyst-enabled processes can create products of higher quality as compared to chemistry-based manufacturing processes	3. Chemistry-based processes can create products of higher quality as compared to Biocatalyst-enabled processes
4. They are pollutionless and easily decomposable at any stage	4. They cant be easily disposed
5. They cannot be practically used in industries.	5. They can be practically used in industries.

Bioenergetics

Bioenergetics is a field in biochemistry and cell biology that concerns energy flow through living systems.

This is an active area of biological research that includes the study of the transformation of energy in living organisms and the study of thousands of different cellular processes such as cellular respiration and the many other metabolic and enzymatic processes that lead to production and utilization of energy in forms such as adenosine triphosphate (ATP) molecules.

Bioenergetics is the study of how energy flows through a living system. Organisms harvest and use energy through photosynthesis and cellular respiration



Bio = life, living

Energetics = study of energy

So, bioenergetics is the study of energy in living things. It includes how energy is transformed (changed from one form into another) throughtwomajorprocesses: cellular respiration and photosynthesis.

For the sake of really understanding what this word means, let's take a closer (but still brief) look at how energy is transformed in cellular respiration and photosynthesis.

Cellular Respiration

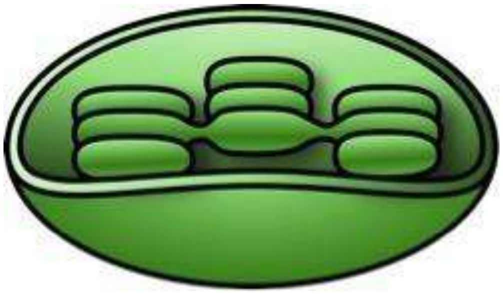
Cellular respiration (or some variation of it) occurs in all living things. Cellular respiration occurs in the cytoplasm and primarily in the mitochondria.

Mitochondria look like lumpy potatoes. The picture here is one mitochondrion cut in half lengthwise. Inside, there are a bunch of folded up membranes (cristae) and liquid goo (matrix).

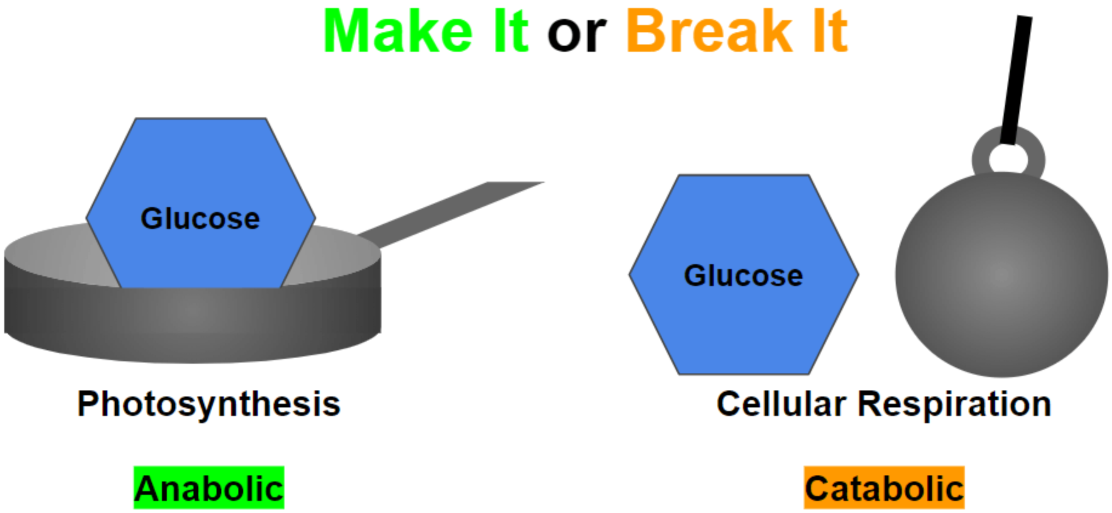
The main purpose of cellular respiration is to take a sugar molecule like glucose (a simple sugar) and break it apart to release energy in the form of ATP.Think of ATP as energy currency. ATP molecules can instantly release energy when the cell needs it.

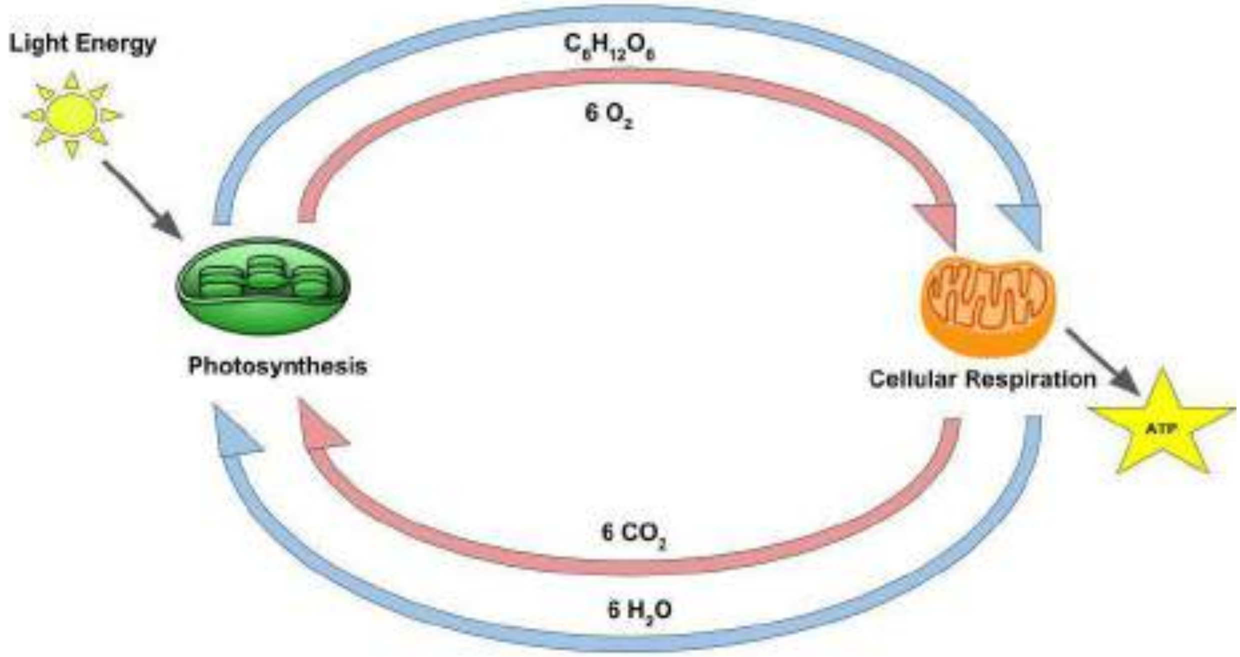
Photosynthesis

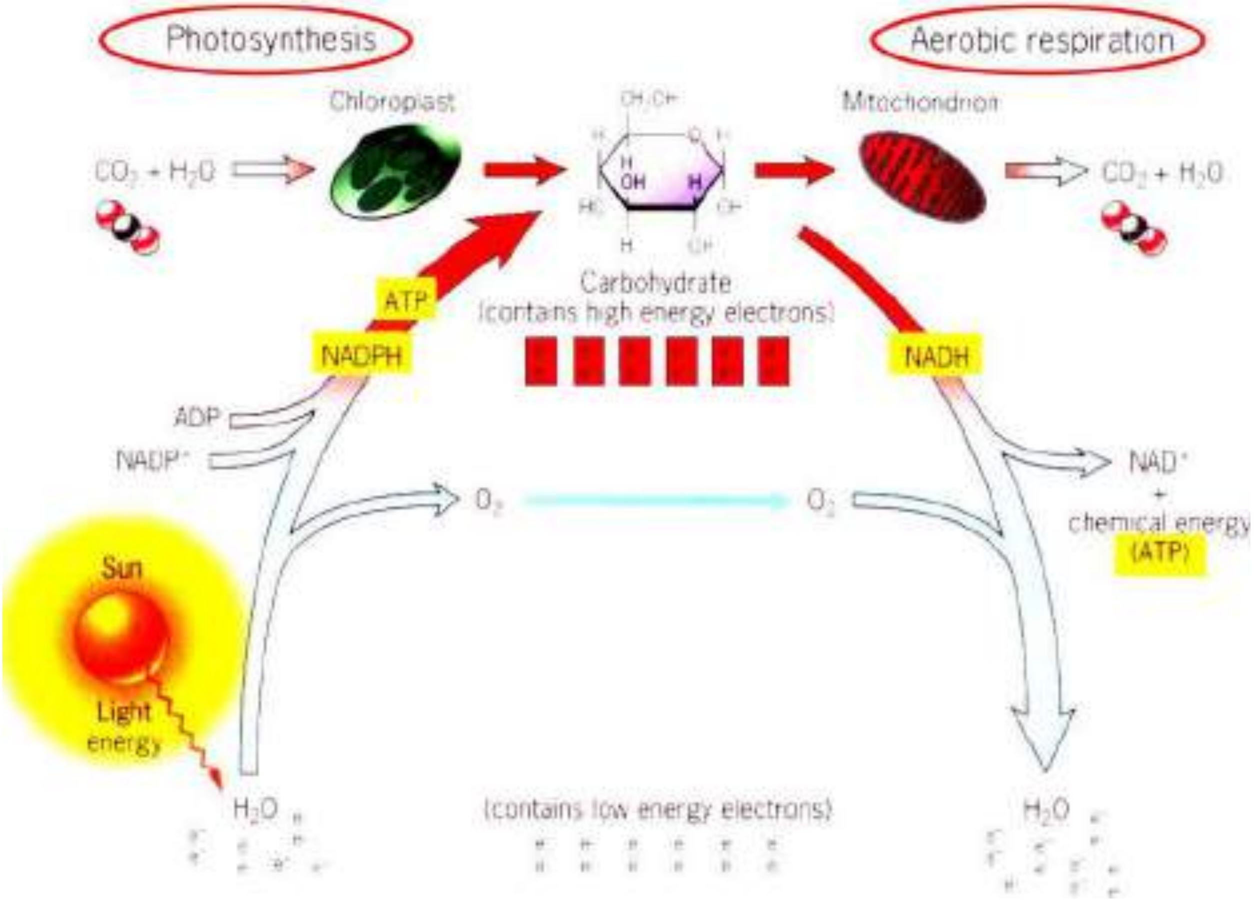
Photosynthesis occurs in most plants, most algae, and some types of bacteria. This process occurs in chloroplast. Chloroplasts are little green organelles in the cell. There's usually more than one of them available to work. In fact, some cells have hundreds of chloroplasts.



In photosynthesis, light (a form of energy), carbon dioxide, and water are transformed into glucose. This is the same glucose that gets broken down in cellular respiration. Funny how it all comes together, isn't it?




Light Energy
$C_6H_{12}O_6$
$6\ O_2$
Photosynthesis
Cellular Respiration
ATP
$6\ CO_2$
$6\ H_2O$


Photosynthesis
Aerobic respiration
Chloroplast
Mitochondrion
$CO_2 + H_2O$
$CO_2 + H_2O$
CH_2OH
H
O
H
H
OH
H
HO
OH
H
OH
Carbohydrate
(contains high energy electrons)
ATP
NADPH
NADH
ADP
$NADP^+$
O_2
O_2
NAD^+
+
chemical energy
(ATP)
Sun
Light
energy
H_2O
(contains low energy electrons)
H_2O

During cellular respiration, the mitochondria break down glucose to harvest chemical energy (ATP). This process is known as catabolism. The prefix cata- means breakdown or downward. We can also recognize the -bolism in metabolism, which refers to change. So, catabolism refers to the breaking down of metabolic compounds

During photosynthesis, the chloroplasts capture and use the light energy from the sun to produce glucose. This process is known as anabolism. The prefix ana- means up, back, or again. We see -bolism come up again here, which refers to change. So, anabolism refers to the formation of metabolic compounds.

Kinetics of product formation

The linear equation of the biogas production rate in the ascending and descending limb can be expressed by the equation given below (Kumar et. al, 2004; Lo et. al, 2010).

It is assumed that biogas production rate will increase linearly with increase in time and after reaching a maximum point after sometime it would decrease linearly to zero with increase in time.

$Y = a + bT$

where, y =biogas production rate in ml/gm/day; T=time in day for digestion;

a (ml/gm/day) and b (ml/gm/day2) are the constants obtained from the intercept and slope of the graph of y vs T.

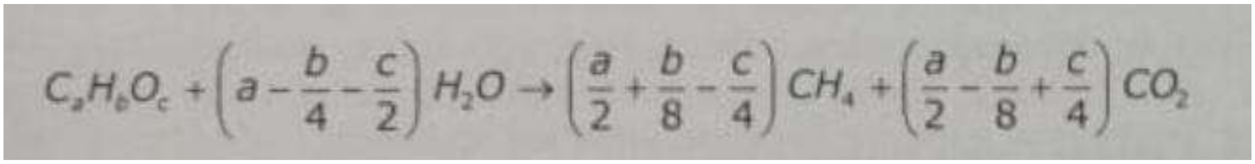
Calculation of Biogas Production

Simple ways to calculate the biogas production of organic matter are the models of Buswell & Mueller (1952), Boyle (1976), Baserga (1998), Keymer & Schlicher (2003) or Amon et al. (2007).

These time independent models are based on data for basic elements or components of organic matter and result only in values for the production of methane and carbon dioxide.

Buswell & Mueller (1952)

If the chemical composition of organic matter is known, the methane and carbon dioxide yield can be calculated with an uncertainty of about 5% using the simple relation:



$$C_aH_bO_c + \left(a - \frac{b}{4} - \frac{c}{2}\right) H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right) CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4}\right) CO_2$$

The degradation of organic matter for the bacteria metabolism (synthesis of cell mass and energy for growth and maintenance) is not included in this relation.
According to this relation, the methane fraction of degraded glucose is, e. g., 50 %:

$$\mathbf{C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2}$$

MODELS WITH REACTION KINETICS

To investigate the kinetics of biogas production, the whole biogas process has to be considered.

1) Growth of microorganisms,
2) Degradation of substrate, and
3) Formation of products.

According to the supply of substrate, processes can be divided into discontinuous and continuous processes.
Discontinuous batch processes are fed only once. Substrate! Degradation and gas production change over the retention time, whereby growth requirements for microorganisms change permanently.

Continuous processes are characterized by the fact that substrate continuously flows in and out of an open system. A process with constant substrate flow and gas production is stationary.

Kinetics of Product Formation

The end product considered fermentation process is biogas. Nevertheless, also a lot of intermediates are very important products. The kinetics of product formation can be calculated based on the kinetics of substrate degradation and of bacterial growth, respectively.
Gaden (1959) investigated fermentation processes and classified products into three types:
Type I: products, which result from primary energy metabolism,
Type II: products, which result from energy metabolism indirectly, and
Type III: products, which obviously do not result from energy metabolism.
Common classifications of products became more detailed today, but using the Classification of Gaden (1959), the kinetics of product formation is well distinguishable (Sinclair & Kristiansen, 1993).

Type I: products, which result from primary energy metabolism.
Type I: the product is produced at the same time as substrate is degraded; an example is the fermentation of alcohol.

Type II: products, which result from energy metabolism indirectly, the product is produced at side reactions or following interactions of direct metabolic products; an example is the fermentation of glucose to lactic acid (Luedeking & Piret, 1959). Therefore, the product formation is delayed and two maxima appear in substrate degradation and bacterial growth.

Type III: products, which obviously do not result from energy metabolism.

Type III: formation of complex molecules (biosynthesis), such as the formation of antibiotics. Energy metabolism is practically complete while the complex product accumulates.

Biocatalysis refers to the use of living (biological) systems or their parts to speed up (catalyze) chemical reactions. In biocatalytic processes, natural catalysts, such as enzymes, perform chemical transformations on organic compounds. Enzymes are biocatalysts- the catalysts of life. A catalyst is defined as a substance that increases the velocity or rate of a chemical reaction without itself undergoing any change in the overall process. Enzymes may be defined as biocatalysts synthesized by living cells. They are protein in nature (exception - RNA acting as ribozyme), colloidal and thermolabile in character, and specific in their action.

Applications of Biocatalyst

In Textile Industry

In olden times, textiles were treated with acid, alkali, or oxidizing agents or soaked in water for several days to breakdown the starch without knowing the role of microorganisms in this process. This practice was difficult to control and sometimes also led to damage or discoloration of the material. Crude enzyme extracts in the form of malt extract, or later, in the form of pancreas extract, was first used to carry out designing, which was followed by enzymes from other sources.

There are a large number of microorganisms that produce a variety of biocatalyst helpful in carrying out many processes. The Textile industry, particularly the chemical processing sector, always has a major share in the global pollution. Biocatalysts play a key role in such alternative processes. The use of biocatalyst in textiles started as long as a century ago. Bacterial amylase derived from *Bacillus* subtilis was used for desizing for the first time by **Boidin** and **Effront** in 1917.

Detergent Biocatalyst

Breakthrough in detergents was made in 1959, when Dr. Jaag, a chemist, developed a new product called Bio 40 that contained a bacterial protease instead of trypsin. Currently, these biocatalyst are manufactured commercially in large quantities through fermentation by common soil bacteria Bacillus subtilis or Bacillus licheniformis. This was made possible in the last two decades by the rapid advances in enzymology and fermentation technology. Although numerous other microorganisms produce proteases and amylases, the types secreted by the above strains have the advantage that they work best at the warm alkaline conditions prevailing in washing liquids. They also must not lose their activity in an environment that contains a multitude of potentially inhibitory chemicals routinely formulated into laundry detergents, such as surface active agents, magnesium or calcium ions, builders (sodium tripolyphosphate), perfumes, and other additives.

Biocatalyst to Convert Sugars from Starch

Initially, fungal amylase was used in the manufacture of specific types of syrup, i.e., those containing a range of sugars, which could not be produced by conventional acid hydrolysis. This practice was changed in the 1960s when an enzyme glucoamylase was launched for the first time; this enzyme was capable of completely breaking down starch into glucose. Later, heat stable alpha amylase development led to further improvement in this process.

A large number of cellulose-, starch-, and sugar-containing plants can be processed to produce sugars and alcohols, such as sugarcane, sweet sorghum, and nipa palm, which are the candidates for the high yield production of alcohol fuel. Likewise, the starch-containing crops such as cassava, sweet potatoes, yams, taro, and tannia are good candidates, but require an additional step to breakdown starch to sugar, the major part of biomass containing cellulose and which, therefore, needs special treatment before it can be used to produce glucose and alcohols. Years of research in biochemistry and biotechnology have boosted knowledge of biocatalyst for industries as well as research and led to the development of new techniques to modify and discover new application of enzymes in medicine, research, and industries. Thus, it has become the need of the day to device efficient methods for enzyme extraction as well as production for commercial purpose.

In Food Industry

Applications in food industries are based on the use of enzymes obtained from various microorganisms. Number of daily used products like cheese, curd, beer and bread are the result of biotechnology. Cheese is traditionally prepared using calf rennet, a protease. Recently, genetically modified microorganisms (E. coli, A. niger) containing calf rennet gene have been developed. In baking and brewing industries, strains of Saccahromyce scerevisae are used for making bread soft and producing beer. Lactic acid bacteria (Lactobacillus sp.) are used in producing dairy products like curd. Similarly, different species of Penicillium are employed to produce different flavoured cheese Pectinases are added into the canned juices to make them clear. Ethanol currently produced by fermenting grain (old technology). Cellulose enzyme technology allows conversion of crop residues (stems, leaves and hulls) to ethanol. Results in reduced CO2 emissions by more than 90% (compared to oil). Allows for greater domestic energy production and it use a renewable feedstock. In Brazil, molasses (a dark syrup obtained from sugarcane) containing fructose and glucose can be fermented into alcohol by yeast. The alcohol is distilled, and mixes with petrol and burned as fuel in motor vehicles. It is known as gasohol. Domestic wastes or biodegradable wastes can be fermented by microorganisms like anaerobic bacteria Methanobacterium spp. to convert it into biogas.

UNIT III

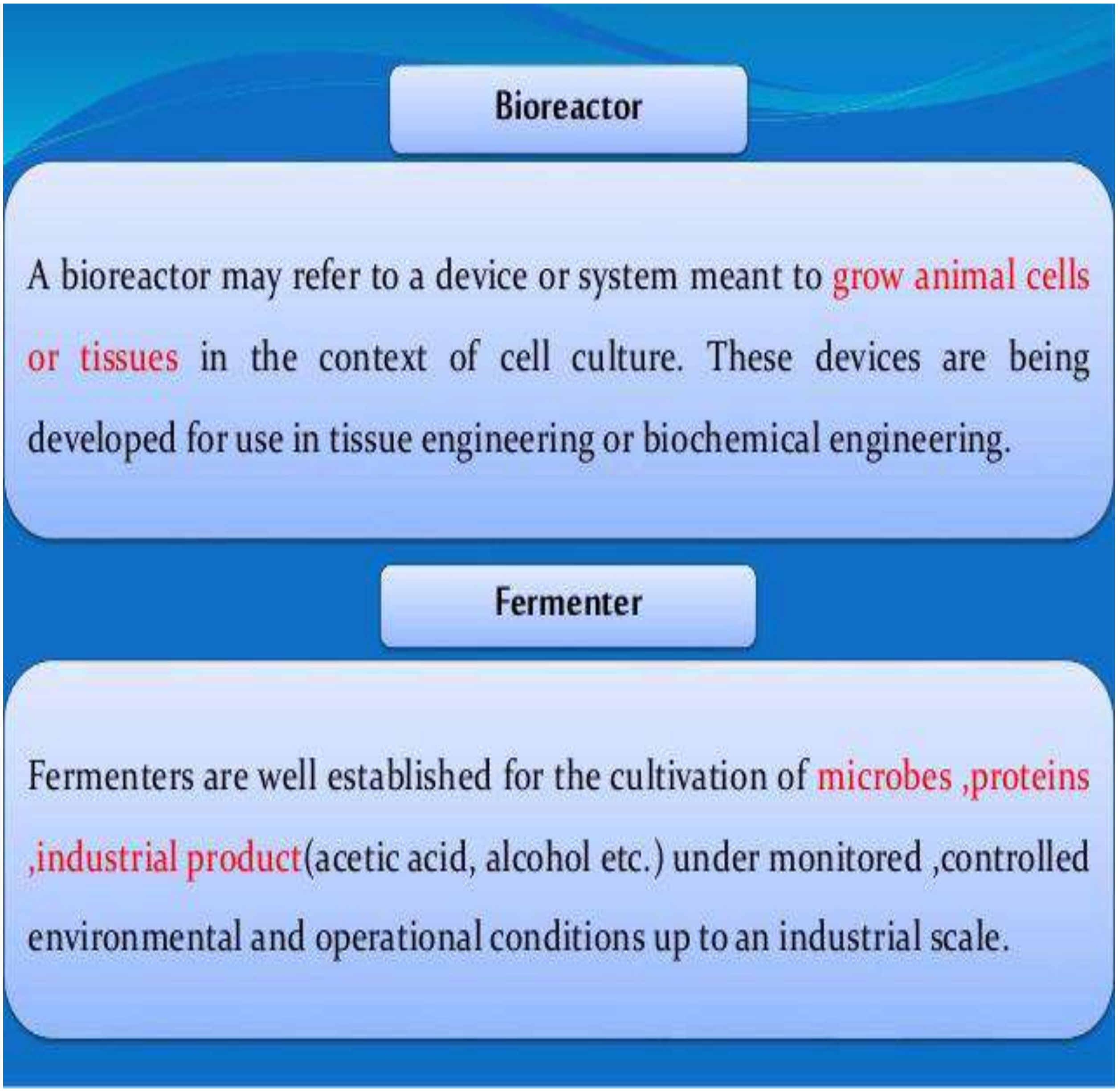
BIO REACTORS AND FERMENTORS

BIOREACTORS

Bioreactor – can be described as a vessel which has provision of cell cultivation under sterile condition & control of environmental conditions e.g., pH, Temperature, Dissolved oxygen etc.

It can be used for the cultivation of microbial plant or animal cells. This process can either be aerobic or anaerobic. The bioreactors are commonly cylindrical, ranging in size from litres to cubic metres, and are often made of stainless steel. Bioreactor is a vessel in which a chemical process is carried out which involves organisms (mainly microbes-viruses or bacteria, fungi and yeasts –traditionally designated as „Fermenters“) or biochemically active substances (enzymes, e.g.) derived from such organisms –in opposite to fermenters frequently considered as „true“bioreactors. This process can either be aerobic or anaerobic. An apparatus, such as a large fermentation chamber, for growing organisms such as bacteria or yeast that are used in the biotechnological production of substances such as pharmaceuticals, antibodies, or vaccines, or for the bioconversion of organic waste. Bioreactor may also refer to a device or system meant to grow cells or tissues in the context of cell culture. Cell culture is the process by which cells are grown under cultivated conditions (animal cells, plant cells, algae). The bioreactor´s environmental condition like gas (oxygen, nitrogen, carbon dioxide) and liquid flow rates, temperature, pH, concentration of substrate and products, cells number and their composition (proteins and nucleic acids), dissolved oxygen levels,, and agitation speed (or circulation rate) need to be closely and continuously monitored and controlled. In many cases, strictly aseptic conditions have to be maintained.

In an aerobic process, optimal oxygen transfer is perhaps the most difficult task to accomplish. There are, limits to the speed of agitation, due both to high power consumption and to the damage to organisms caused by excessive tip speed. On the basis of mode of operation, a bioreactor may be classified as batch, fed batch or continuous. On the basis of mode of flow of fluids a bioreactor may be classified as CSTR bioreactor (continuous flow stirred reactor-the content of the bioreactor is ideally mixed), bioreactor with piston flow and bioreactors with non- ideal flow of fluids (cascade of ideal mixtures, dispersed flow of fluids). The quality of flow of fluids significantly influences the rate of grow of cells and the degree of conversion of substrate and consequently, the yield and selectivity of the products. On the basis of a number of phases treated into the bioreactor we can distinguished homogeneous bioreactors (e.g. one phase tubular bioreactor with enzyme diluted in the liquid substrate) and heterogeneous bioreactors (e.g. two phase solid-liquid bioreactor like the column type bioreactor with immobilized enzyme and liquid substrate and/or three phase bioreactors with submersed culture: gas (air bubbles)-liquid (substrate)-solids (cells). An apparatus (usually jacketed cylindrical SS vessel) for growing organisms such as bacteria, viruses, or yeast that are used in the production of pharmaceuticals, antibodies, or vaccines, or for the bioconversion of organic wastes. Under optimum conditions of gas (air, oxygen, nitrogen, and carbon dioxide) flow rates, temperature, pH, dissolved oxygen level, and agitation speed, the microorganisms or cells will reproduce at a rapid rate.

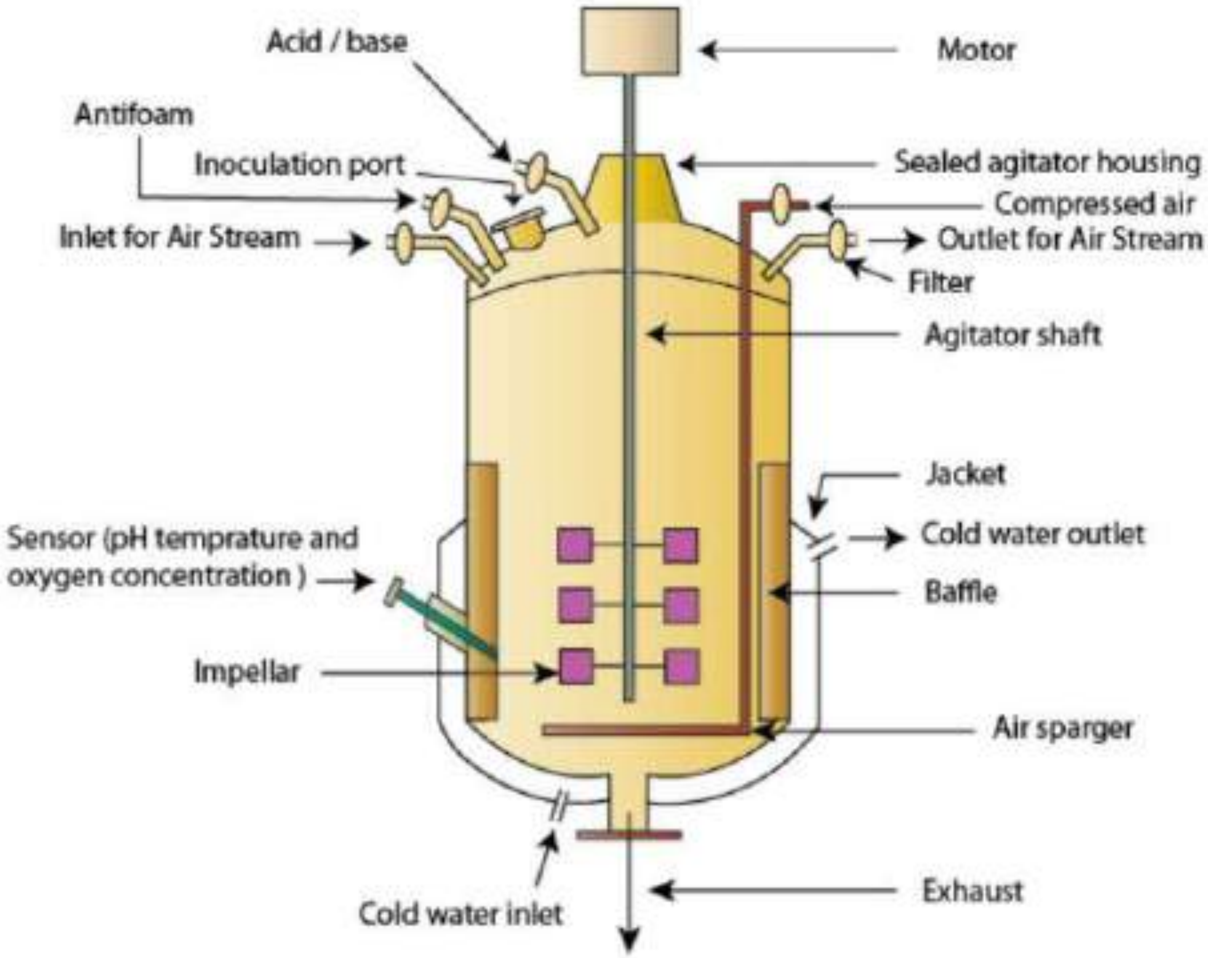


Bioreactor

A bioreactor may refer to a device or system meant to grow animal cells or tissues in the context of cell culture. These devices are being developed for use in tissue engineering or biochemical engineering.

Fermenter

Fermenters are well established for the cultivation of microbes ,proteins ,industrial product(acetic acid, alcohol etc.) under monitored ,controlled environmental and operational conditions up to an industrial scale.



OPERATIONAL STAGES IN A BIO-PROCESS

There are three main stages to a bio-process – these consist of; upstream processing, bioreaction and downstream processing to change the raw material to a finished product.

Upstream Processing, Bioreaction, Downstream Processing

Upstream processing

The raw material can be of biological or non-biological origin. Firstly, it is changed to a more suitable form for processing. This is completed in the upstream processing stage. This stage involves;

Chemical hydrolysis, Preparation of liquid medium,Parting of particulate, Air purification, other preparatory operations

Bioreaction

After upstream processing step, the resulting feed is transferred to one or more Bioreaction stages. The Biochemical reactors or bioreactors form the base of the Bioreaction step. The bioreaction stage consists of three operations; Production of biomass, Metabolise biosynthesis

Biotransformation

Downstream processing

Finally, the material produced in the bioreactor must be further processed in the downstream section to convert it into more useful form. This process consists of physical parting operations which comprise of; Solid liquid separation, Adsorption, Liquid-liquid extraction, Distillation, Drying.

Types of Bioreactor Processes

Batch, Continuous and Fed-batch**.**

Batch Bioreactor Processes

Batch bioreactor processes involves filling the bioreactor with medium and inoculum and working the reactor without adding nutrients or medium until after the growth profile is complete.

Continuous Bioreactor Processes

Continuous bioreactor processes involve the reactor being continually fed nutrients and medium into the vessel, as the reactor is continually harvesting material. As there is material constantly being collected, continuous processes can result in bigger volumes of harvested material and longer bioreactor campaigns. The downside to longer bioreactor campaigns is that it significantly increases the possibility of contamination.

Fed-Batch Bioreactor Processes

Fed-batch bioreactor processes are the most common reactor processes used. The process begins with a lower starting volume and feeds nutrients and medium on a planned schedule without removing the harvest material. After the process is completed, the material is harvested for downstream processing.

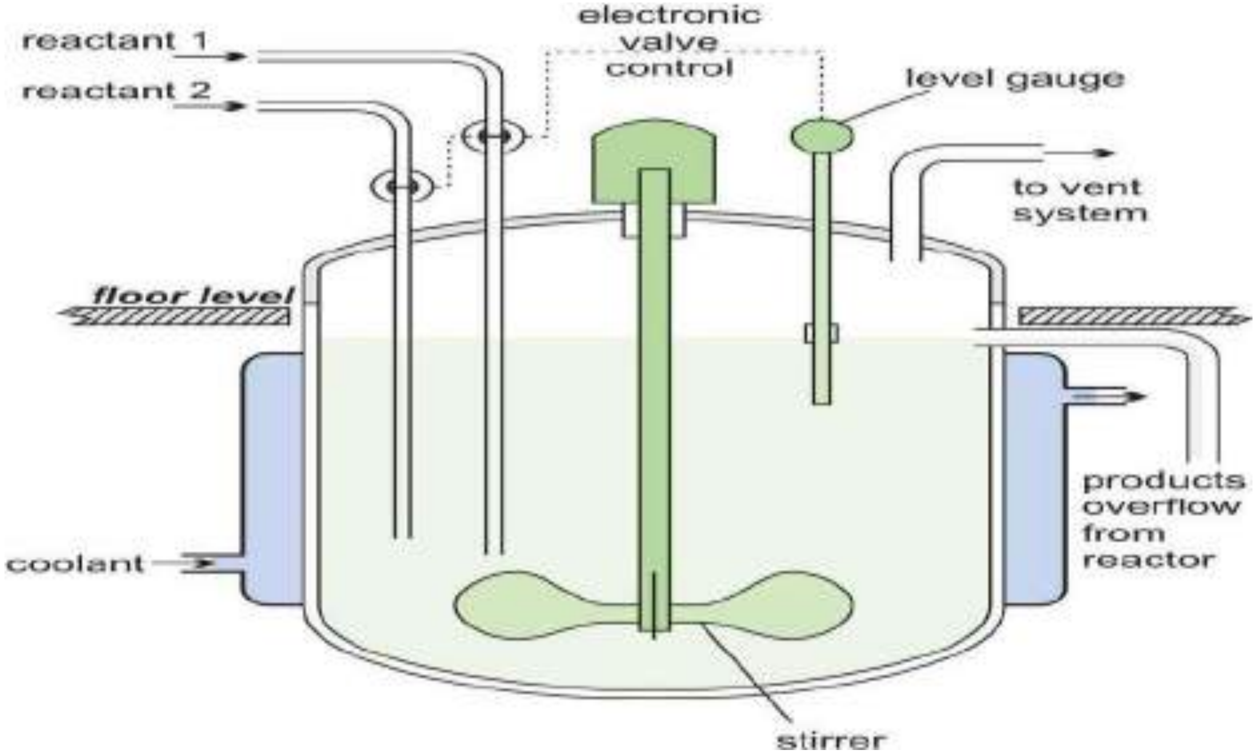
CONTINUOUS STIRRED TANK BIOREACTORS – batch type

A continuous stirred tank bioreactor consists of a cylindrical vessel with motor driven central shaft that supports one or more agitators (impellers). The shaft is fitted at the bottom of the bioreactor. The number of impellers is variable and depends on the size of the bioreactor i.e., height to diameter ratio, referred to as aspect ratio.

The aspect ratio of a stirred tank bioreactor is usually between 3-5. However, for animal cell culture applications, the aspect ratio is less than 2. The diameter of the impeller is usually 1/3 rd of the vessel diameter. The distance between two impellers is approximately 1.2 impeller diameter. Different types of impellers (Rustom disc, concave bladed, marine propeller etc.) are in use.

In stirred tank bioreactors or in short stirred tank reactors (STRs), the air is added to the culture medium under pressure through a device called sparger. The sparger may be a ring with many holes or a tube with a single orifice. The sparger along with impellers (agitators) enables better gas distribution system throughout the vessel. The bubbles generated by sparger are broken down to smaller ones by impellers and dispersed throughout the medium. This enables the creation of a uniform and homogeneous environment throughout the bioreactor.

The Continuous Stirred Tank bioreactor is the classical design and still the most widely used bioreactor. Most production facilities and FDA approved production processes for biopharmaceuticals are based on the stirred tank bioreactors. The scale-up process from laboratory to production sized systems is therefore based on this design as well. This cylindrical bioreactor uses a top or bottom mounted rotating mixing system. The aspect ratio is usually between 3-5.



ADVANTAGES OF STRS

Continuous operation, Good temperature control

Easily adapts to two phase runs, Good control over parameters and environment, Simplicity of construction

Flexible and Low operating (labor) cost and investment needs

Easy to clean

Can cope up with high concentrations due to superior heat transfer

Efficient gas transfer to growing cells and mixing of the contents.

DISADVANTAGES OF STRS

The need for shaft seals and bearings.

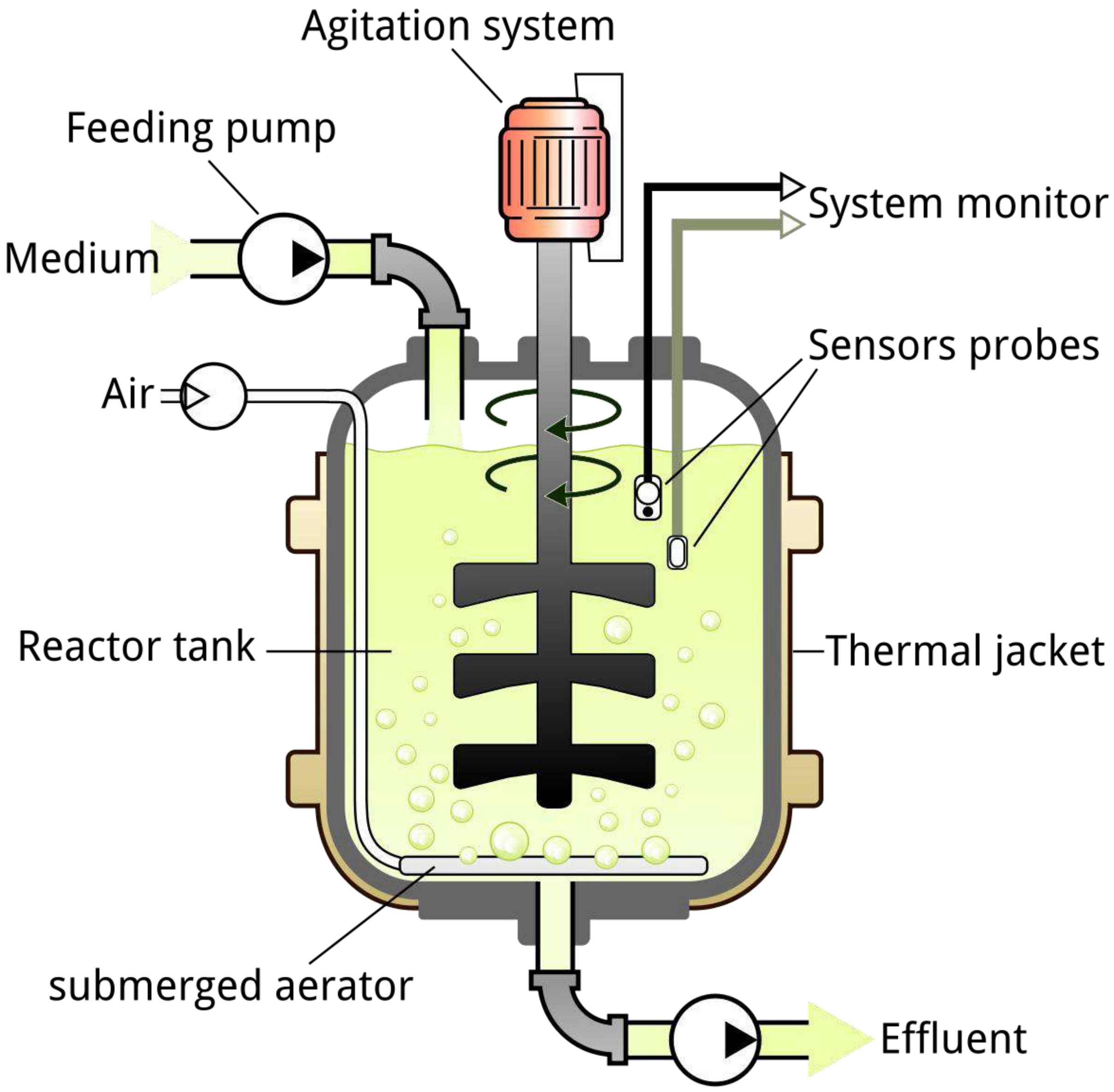
Size limitation by motor size, shaft length and weight.

Foaming is often a problem.

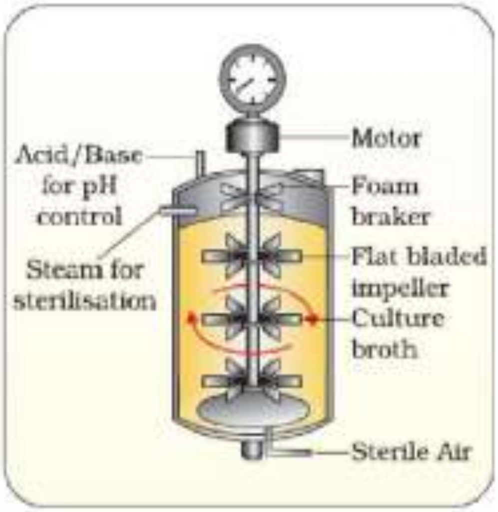
Consumption of power is more due to the mechanical pressure pumps.

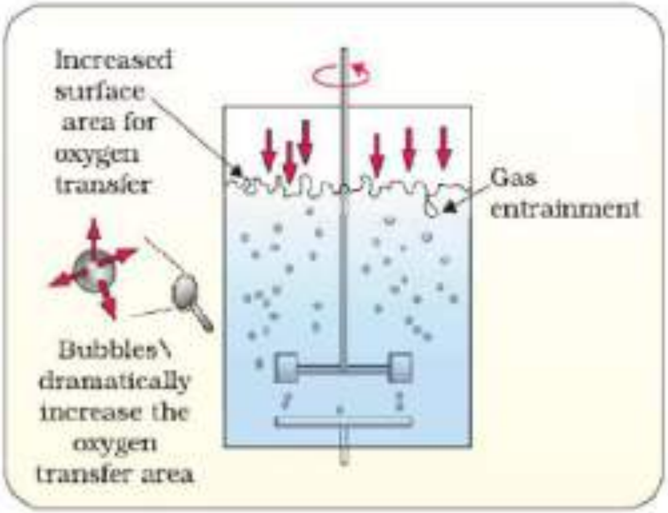
Application

The most successful continuous systems to date have been those employing yeasts and bacteria, in which the desired products are the cells. Production of primary metabolites, enzymes and amino acids. The production of alcohol (product clearly associated with growth or energy producing mechanisms). The most widely used is the activated sludge process used in waste water treatment industry.



General structure of a continuous –stirred –tank-type bioreactor





Bioreactors for Animal and Plant Cells

Waste Water Treatment

Domestic effluent consisting of black water and gray water. Water from commercial establishments and institutions, including hospitals. Industrial effluent, storm water and other urban run-off. Agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter.

Objective

Wastewater treatment is a process used to remove contaminants from wastewater or sewage and convert it into an effluent that can be returned to the water cycle with acceptable impact on the environment,orreusedforvariouspurposes (called water reclamation).

Impacts of Waste Water

Water pollution, Loss of blue carbon sink, Ecological Imbalance

Biodiversity, Loss of fisheries livelihood, Climate change

Waste water characteristics

Physical-solids, color, temperature, odor

Chemical- pH, alkalinity, organic matter, heavy metals, refractory organics, nutrients

Biological-Bacteria, virus, protozoa, helminths

Biochemical oxygen demand

Biochemical oxygen demand, or BOD, refers to the amount of dissolved oxygen needed by aerobic biological organisms to break down organic matter into smaller molecules. High levels of BOD indicate an elevated concentration of biodegradable material present in the wastewater and can be caused by the introduction of pollutants such as fecal waste, cleaning, and wash-down from food processing or fertilizer runoff.

Nitrates and phosphates

If large amounts of nitrates and/or phosphates are not removed from wastewater and these nutrients are discharged into local environments, they can lead to an increase BOD and extensive weed growth, algae, and phytoplankton. This can further lead to eutrophication, or the deoxygenation in a body of water, killing the organisms and potentially leading to hypoxia or environmental dead zones.

Pathogens

Pathogens are bacteria, viruses, fungi, or any other microorganisms that can be present in wastewater that can lead to all kinds of health issues, including acute sickness, severe digestive problems, or death. When domestic or industrial wastewater contains these harmful pathogens and is not treated, it can spread illnesses and diseases such as cholera, dysentery, salmonellosis, hepatitis A, botulism, and giardiasis, to name a few.

Metals

Mostly found in wastewater as a result of various industries, manufacturing processes, when left in wastewater in high concentrations, metals can cause extensive damage to the environment and human health. They are particularly damaging because they don't break down and tend to accumulate, causing toxic environs.

Total suspended solids

Total suspended solids (TSS) in wastewater, the organic and inorganic solid material suspended in the water, can, like many of the other contaminants listed. They can also be problematic if the wastewater is being reused for a process, so depending on whether or not you need to discharge your wastewater in a publicly owned treatment works (POTW) or environment, or reuse the wastewater for process, will determine how harmful the TSS will be. TSS can decrease levels of oxygen in aquatic environments and kill of insects. They can also scale and foul piping and machinery.

Total dissolved solids

Total dissolved solids (TDS) are any anions, cations, metals, minerals, or salts found in wastewater. They can cause issues with aquatic life, irrigation and crops, and they can also seep into groundwater. TDS can be generated in wastewater from just about any industry.

Synthetic chemicals

When pesticides and other chemicals are used / made in the manufacturing process, they can be transmitted to humans and the environment through wastewater, causing damage to the environment and human health. Some common chemicals found in wastewater include diethylstilbestrol, dioxin, PCBs, DDT, and other pesticides. These “endocrine disruptors” can block hormones in the body and affect the functions these hormones control.

Process of Wastewater Treatment

Primary treatment

To remove coarse solid particles, remove suspended, easily settle able and floating material, Primary sedimentation tank (Primary clarifier).

Secondary treatment

Oxidation of organic compounds, Remove suspended, colloidal and dissolved organic and inorganic matter, Biological treatment (ASP) Activated Sludge Process, Trickling filter, RBC-Rotating biological contactors), chemical-physical processes. Removal of dissolved organics and remaining 40-50% suspended solids (which are not removed in primary treatment) Biological processes are commonly used as secondary treatment to remove organics. Biological Process is the process which decomposition of organic matter using microorganism into acceptable end products.

Advanced treatment

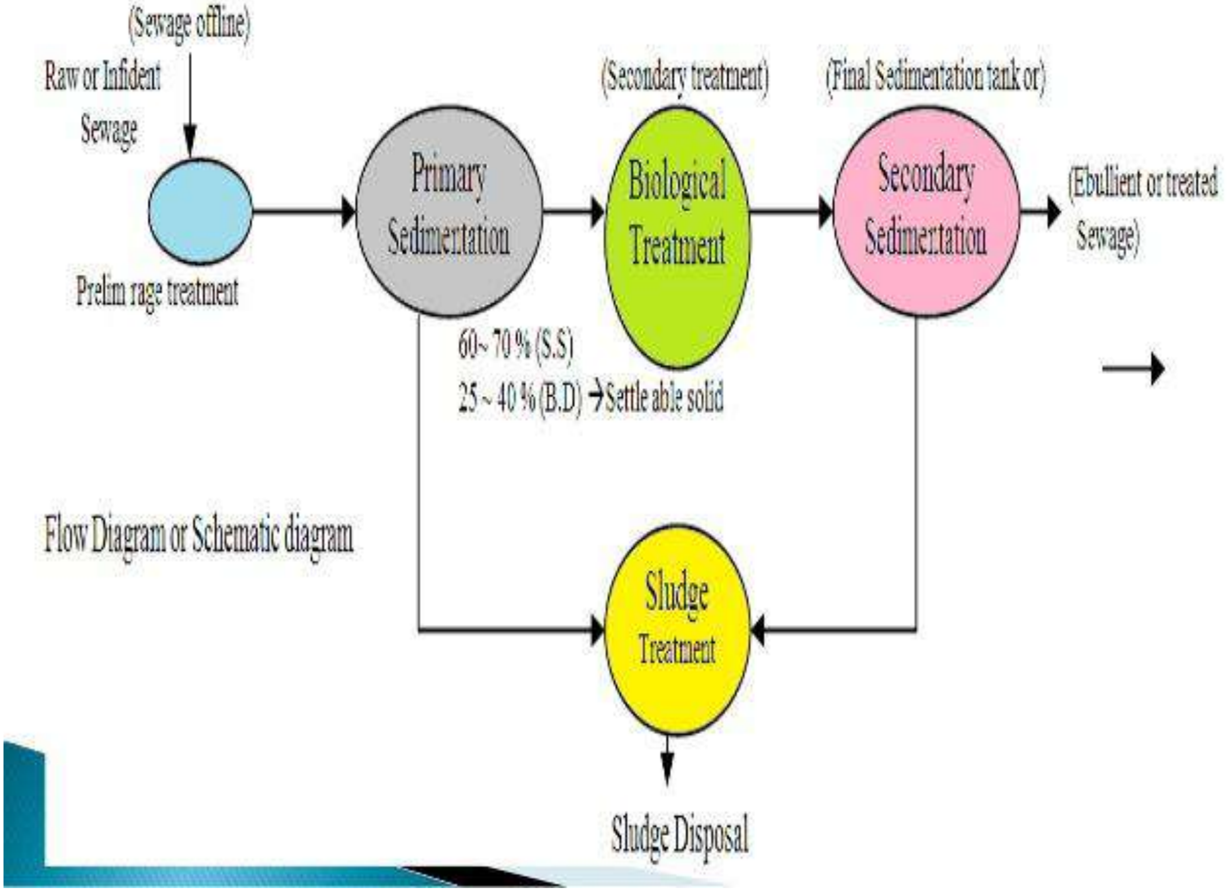
Removes objectionable substances, polishing the secondary treated effluent to meet the reuse / discharge requirements. Absorption, Advanced oxidation, disinfection.

Final treatment

Disinfection and disposing

Sludge processing

Stabilize the sludge



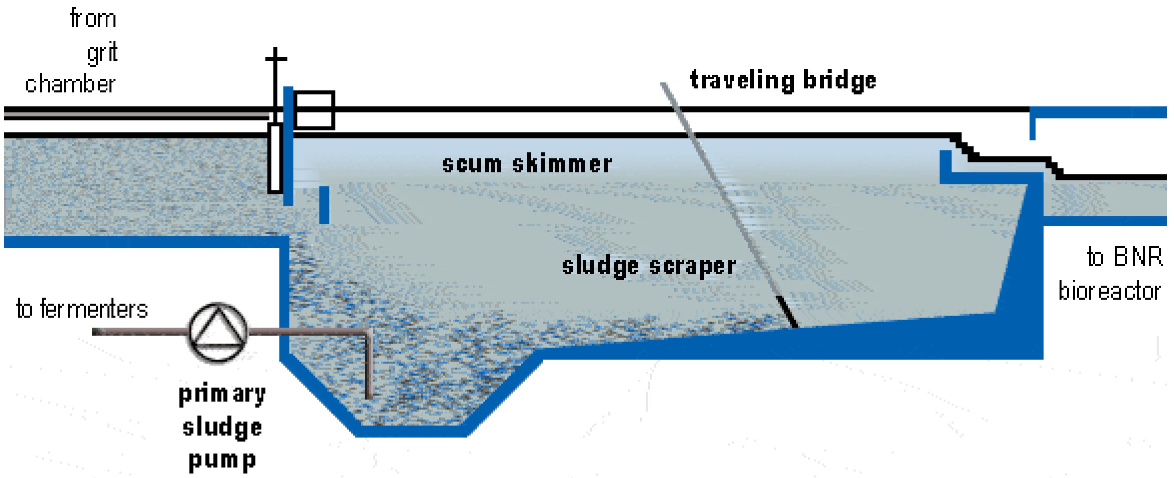
Primary Treatment

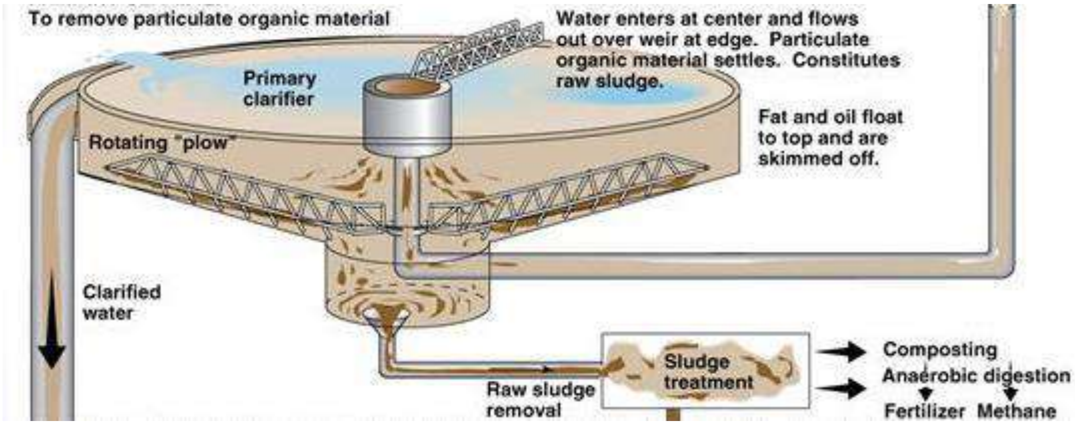
Sedimentation

Most of the settle able solids are separated or removed from the wastewater by the physical process of sedimentation. Physical phenomena relating to the settling of solids by gravity are allowed to operate. To remove larger entrained objects. Concentration and collection of particulate matter referred to as sludge.

Removes readily settleablesolids and floating materials, TSS reduction –50 to 60%BOD reduction –25 to 40%Organic material is slightly heavier than water and it settle slowly (1 to 2.5m/s) to the bottom of tank under gravitational force. Follows Type-2 settling.

Primary Sedimentation Tank





Secondary Treatment

Secondary treatment depends primarily upon aerobic organisms which biochemically decompose the organic solids to inorganic or stable organic solids .The devices used in secondary treatment may be divided into four groups:

Trickling filters with secondary settling tanks

Activated sludge and modifications with final settling tanks

Intermittent sand filters, Stabilization ponds

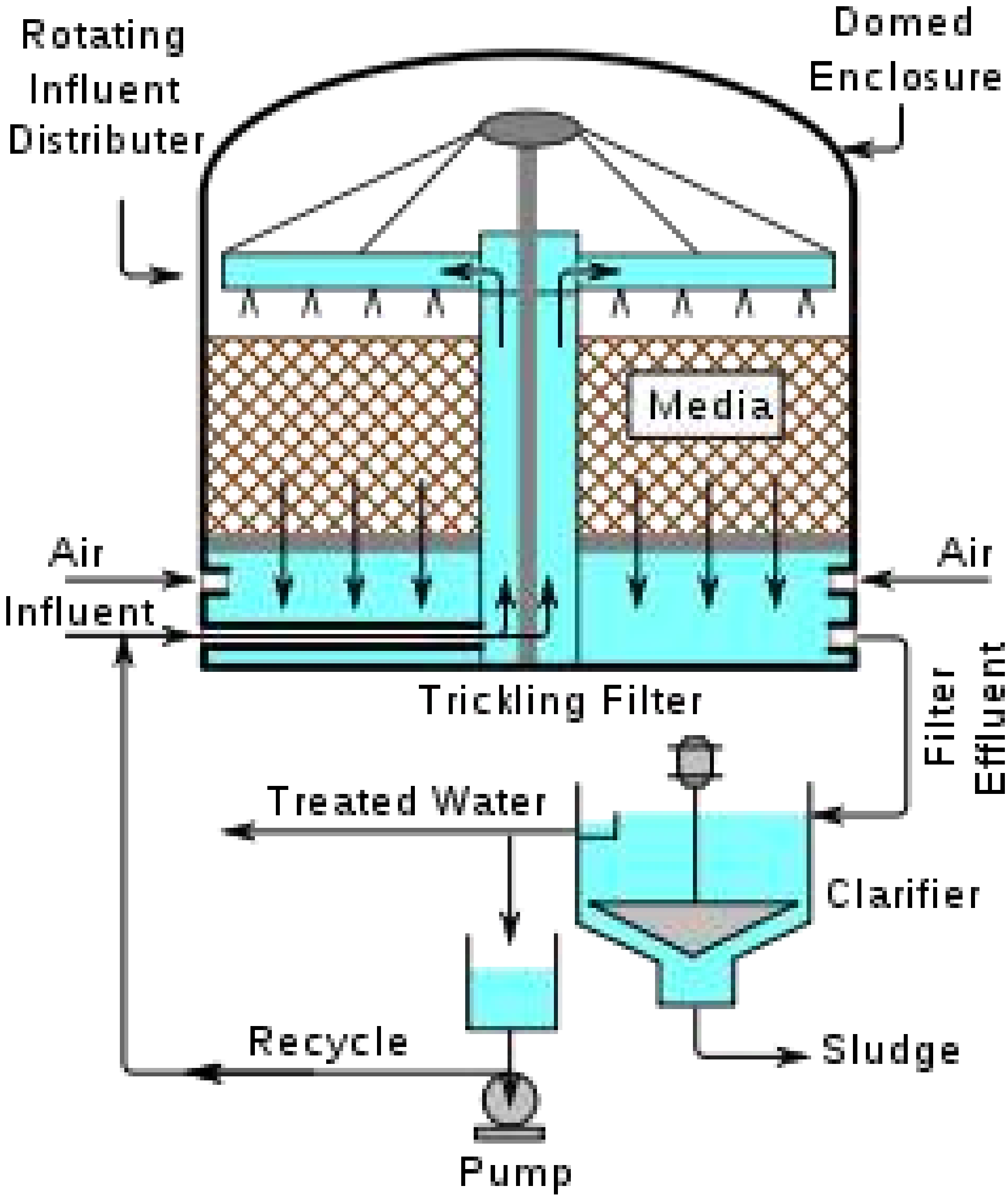
Trickling Filters Method

It consists of a bed of coarse pieces of stone, gravel and slag. The depth is 1 to 3 inches. The tank is equipped with drains underneath. The surface of the filter is applied with mixed population of micro organisms. Passage of wastewater through the filter causes the development of a gelatinous coating of bacteria, protozoa and other organisms on the media. on-submerged fixed film biological reactor, Attached culture biological system, A reactor in which randomly packed solid (rock or plastic) provide surface area for biofilm growth, Sorption and biological oxidation are the primary means of food removal.

Ideal filter packing
High specific surface area per unit volume

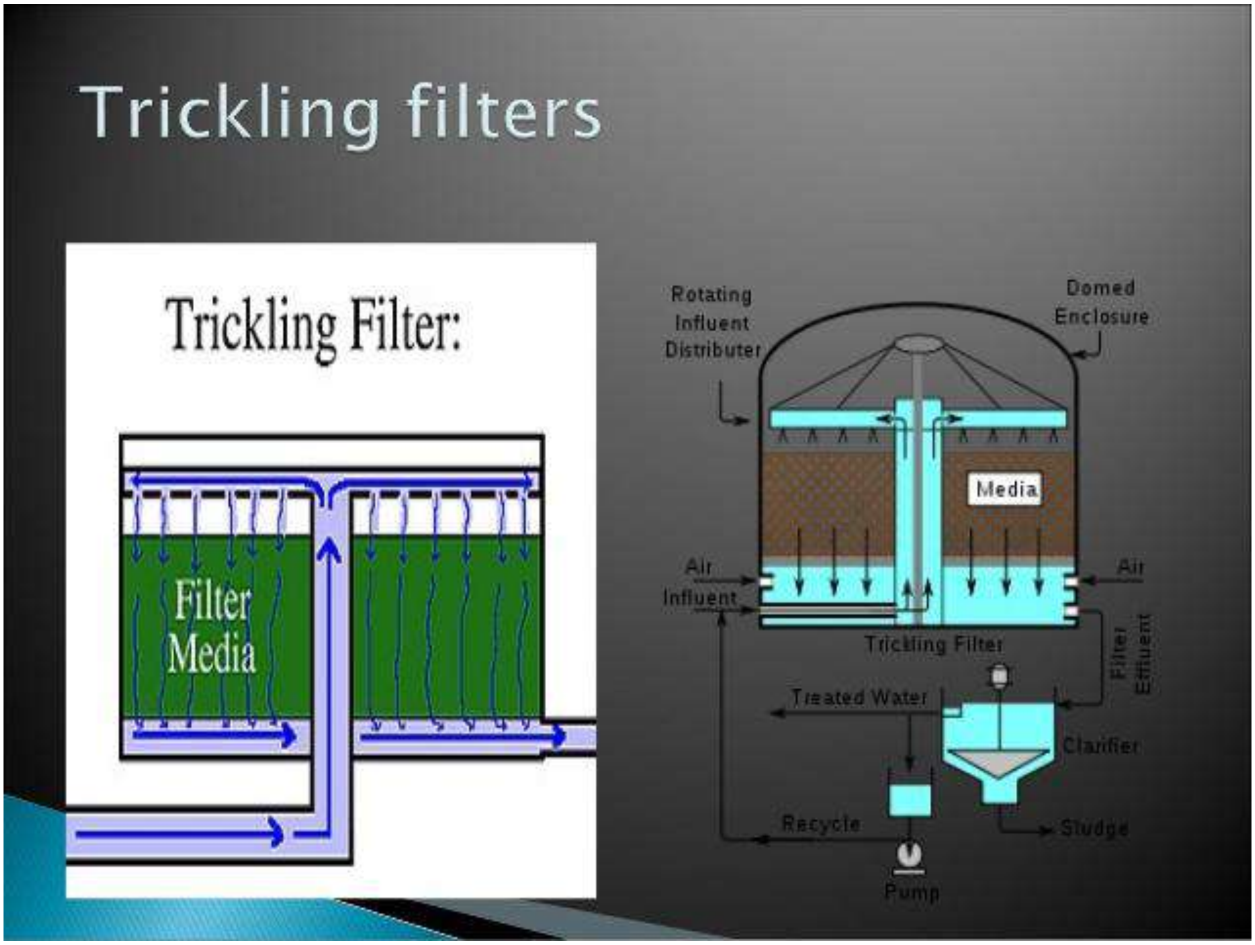
Low in cost, high durability, high enough porosity

Chemically resistant surfaces, Hard

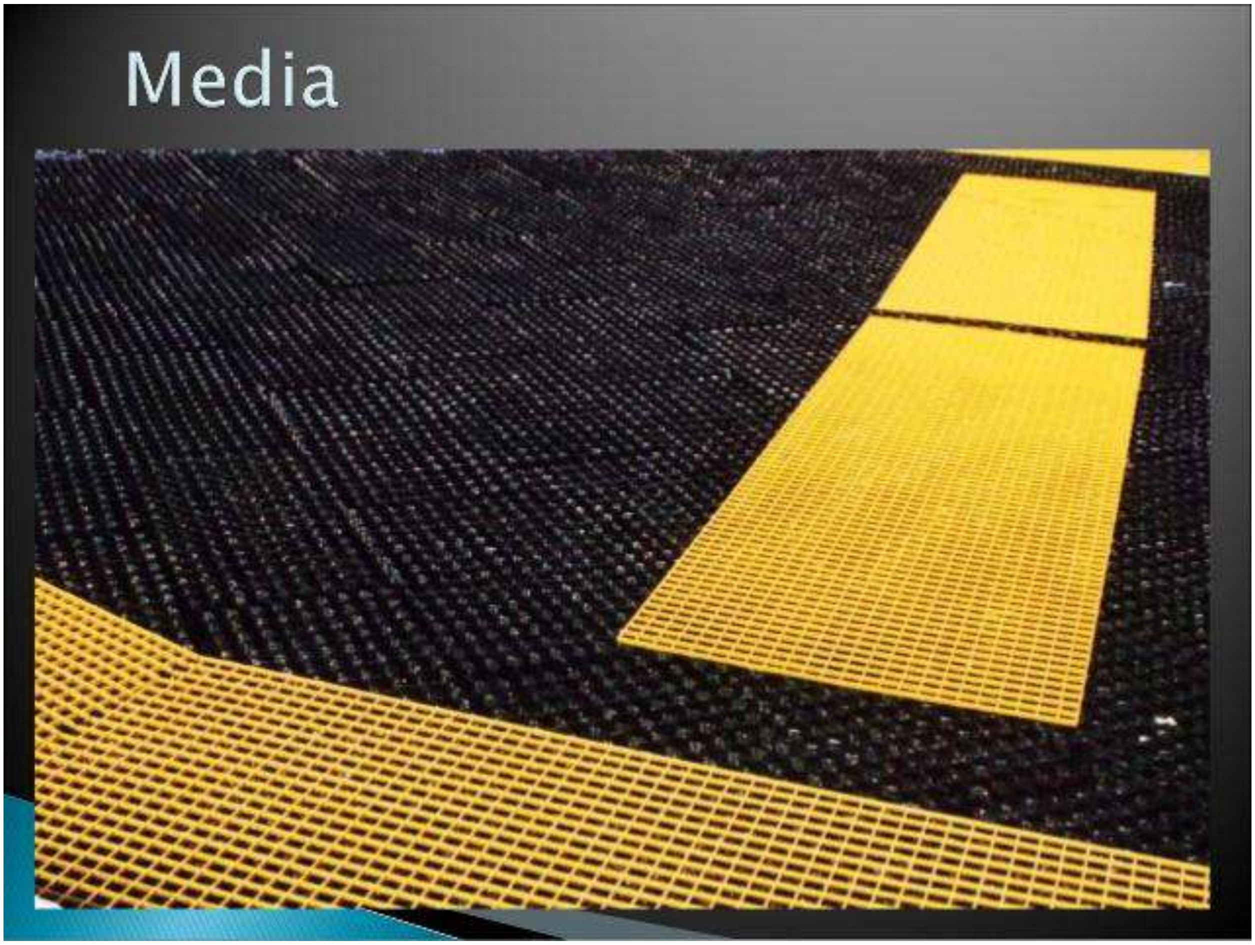

Rotating Influent Distributer
Domed Enclosure
Media
Air
Influent
Air
Filter Effluent
Trickling Filter
Treated Water
Clarifier
Recycle
Sludge
Pump

Trickling Filters

Trickling Filters



Trickling filters



Media

In the absence of oxygen, anaerobic decomposition becomes active near the surface of the media.

Settled waste+o_2 = oxidized fluid + new cells

The new cells exert high BOD and must be removed before effluent is discharged to a natural water body.

For greater efficiency biofilters recirculation of sewage, plastic media etc., are employed.

Advanced/Tertiary Treatment Processes

Processes for Nutrient Removal, Biological Phosphorus Removal

Chemical Precipitation of Phosphorus, Nitrogen Removal (Denitrification).Reduce the nutrient content of wastewater to prevent uncontrolled algae growth in lakes, reservoirs, or streams**.**

Disinfection

Kill or inactivate pathogenic organisms in the treated effluent prior to discharge to the receiving stream. Processes for Disinfection, Chlorination.

Lagoon

They are also known as oxidative ponds or stabilizing ponds .It is most important method of sewage treatment in hot climates where sufficient land is normally available. The sewage effluent are been dumped into large pond of depth 2- 4feet .It is natural process of sewage purification because oxidation of matters occur through symbiotic action of algae and aerobic bacteria. Oxygen is provided by artificial aeration (mechanical aerators).Lagoons are classified as Aerobic lagoons and Facultative lagoons (according to the degree of mechanical mixing).

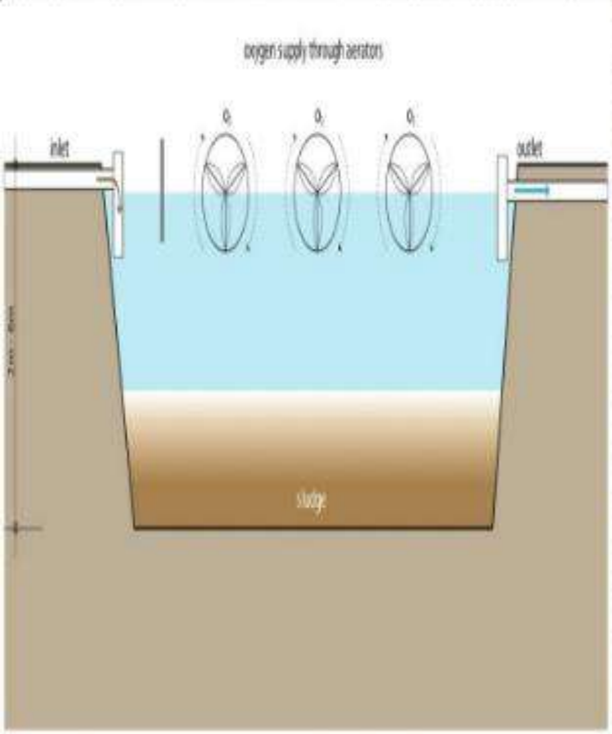
Aerobic lagoons

Sufficient energy is supplied both to meet the oxygen requirement and to keep the entire tank content mixed and aerated.

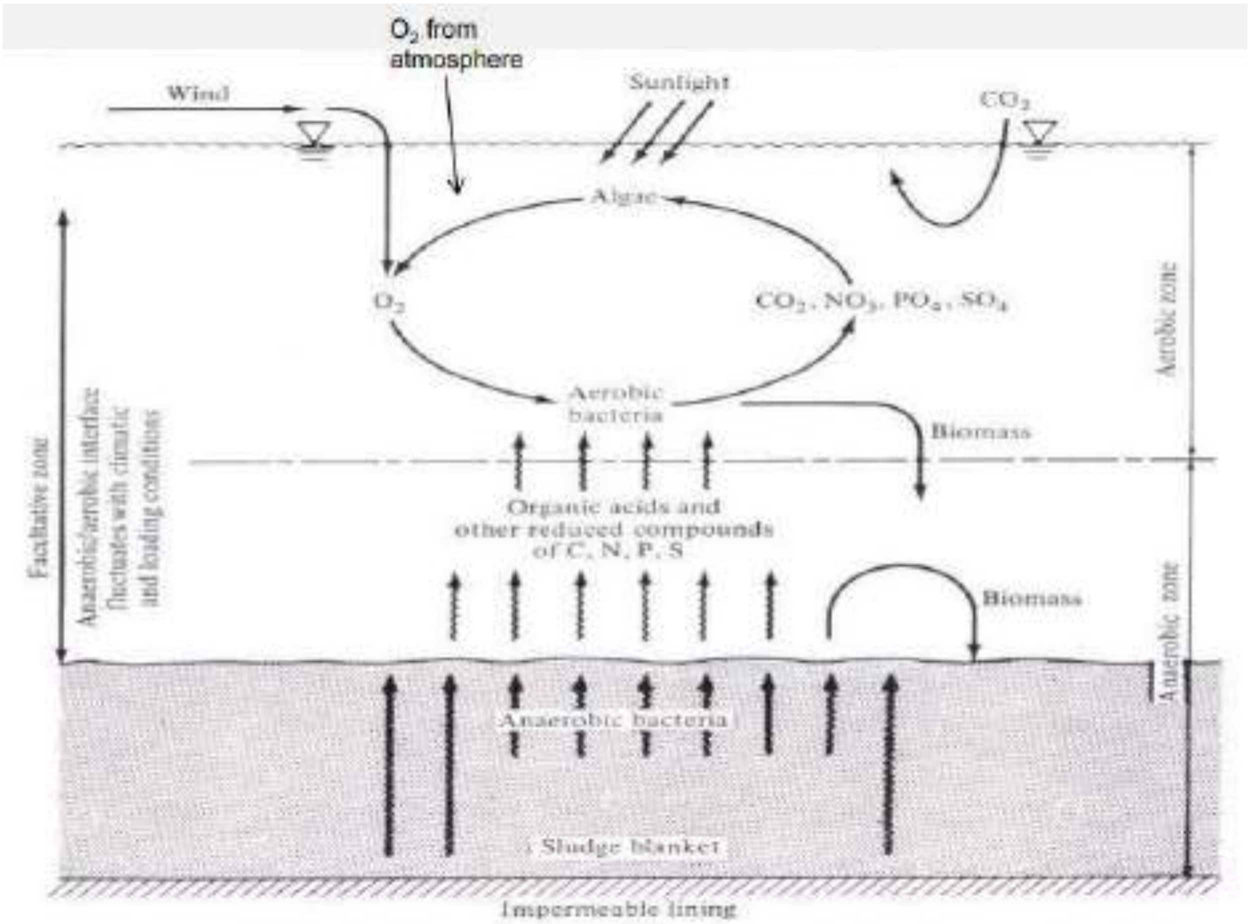
Facultative lagoons

Energy input is only sufficient to transfer the amount of oxygen required for biological treatment but is not sufficient to maintain the solids in suspension. A portion of incoming solids will settle along with a portion of biological solids produced from the conversion of the soluble organic substrate. In time, settled solids will undergo anaerobic decomposition. Eventually facultative lagoons must be dewatered and the accumulated solids are removed

Aerated lagoon



Treatment plant



ADVANTAGES

Any degree of purification at lowest cost.

Removal of pathogens is greater.

Wide variety of industrial waste.

The algae produced are potential source of high protein food.

They can be easily designed.

DISADVANTAGES

Large land space.

Inefficient for removing fecal bacteria

Algae may die, & if not removed may become organic matter of sewage effluent.

Final treatment

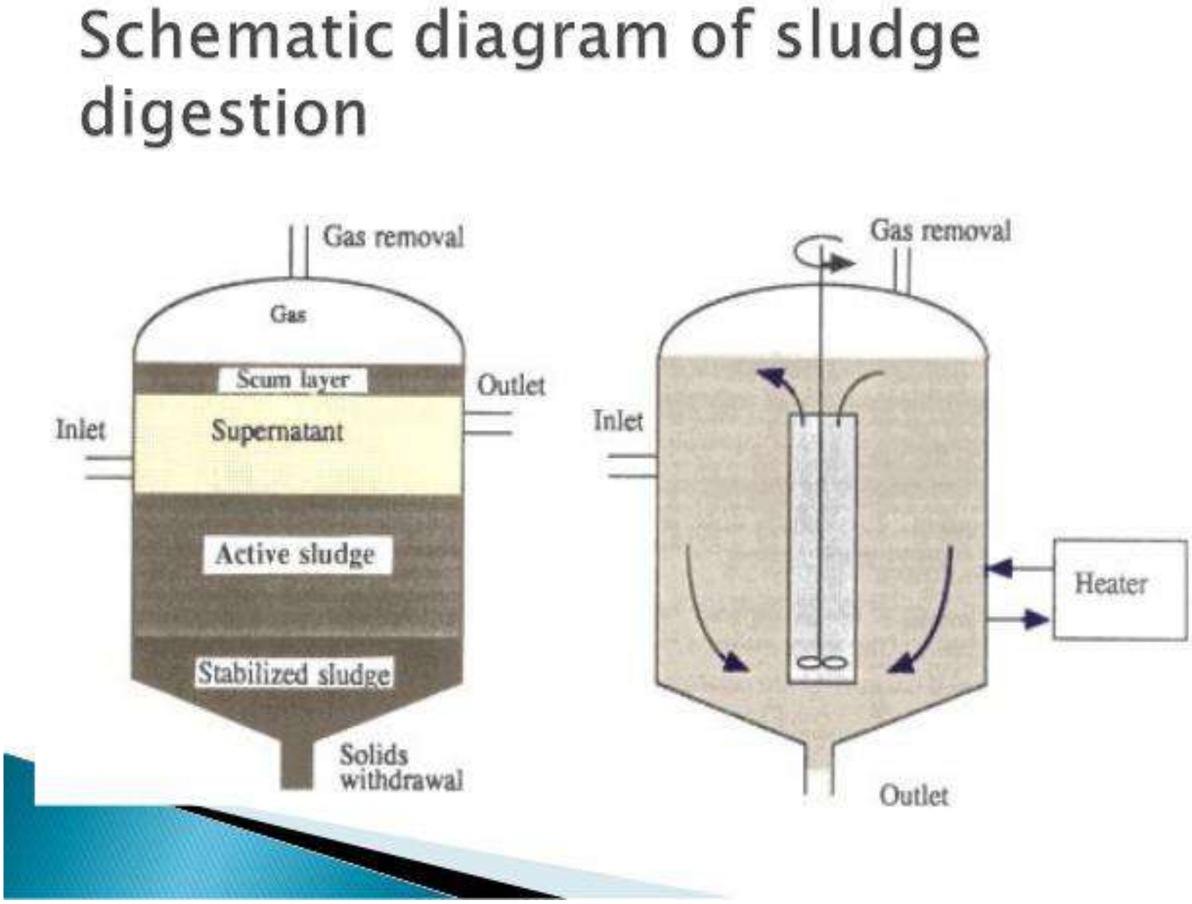
Composting

It is a process where dewatered sludge undergoes decomposition within thermophilic temperature range. The dewatered sludge is mixed with a bulking agent such as wood chips and kept in aerated piles. The mixture is allowed to cure for a period of time (21 days). It is finally transformed to humus type material and used soil conditioner.

Sludge is settleable solids separated from liquids during processing, or deposits of foreign materials on the bottoms of streams or other bodies of water.

Sludge processing

The solids accumulated during sedimentation are pumped into separate tank for digestion of sludge under controlled condition. The microbial action on sludge is known as sludge digestion. Anaerobic and facultative bacteria degrade the solids to methane and CO_2 and traces of nitrogen and hydrogen. This gas mixture is used as fuel for heating and for operating power.



Schematic diagram of sludge digestion

ACTIVATED SLUDGE PROCESS

Activated sludge is a process in which air or oxygen is forced into sewage liquor to develop a biological floc which reduces the organic content of the sewage. (Ruthven et al., 1993) .The sludge is returned to the aeration system to re-seed the new sewage entering the tank. The most conventional unit for the aerobic biological treatment of wastewater. Two Parts-Aeration tank and Secondary sedimentation tank (SST).Aeration Tank-where organic matter stabilized by the action of bacteria under aeration.SST-where the sludge (biological cell mass) is separated from the effluent of aeration tank and the settle sludge (25 to 50 %) is recycled partly to the aeration tank and remaining wasted. Aeration conditions are achieved by use of diffused or mechanical aerators. Diffuser-Provided at the tank bottom. Mechanical aerators-Provided at the surface of water (either floating or fixed).Design parameters-Aeration period, BOD loading, MLSS, Food-to-microorganism ratio (F/M), SRT etc.

Floc

A floc is a type of microbial aggregate that may be contrasted with biofilms and granules, or else considered a specialized type of biofilm. Flocs appear as cloudy suspensions of cells floating in water, rather than attached to and growing on a surface like most biofilms.

Components of ASP

Aeration basin

Wastewater comes in contact with active microbial biomass for treatment, Bioflocculation, biosoprtion and biooxidation occur, Organic matter is transformed into biological flocs Suspended and colloidal solids become integral part of flocs.

Aeration and mixing

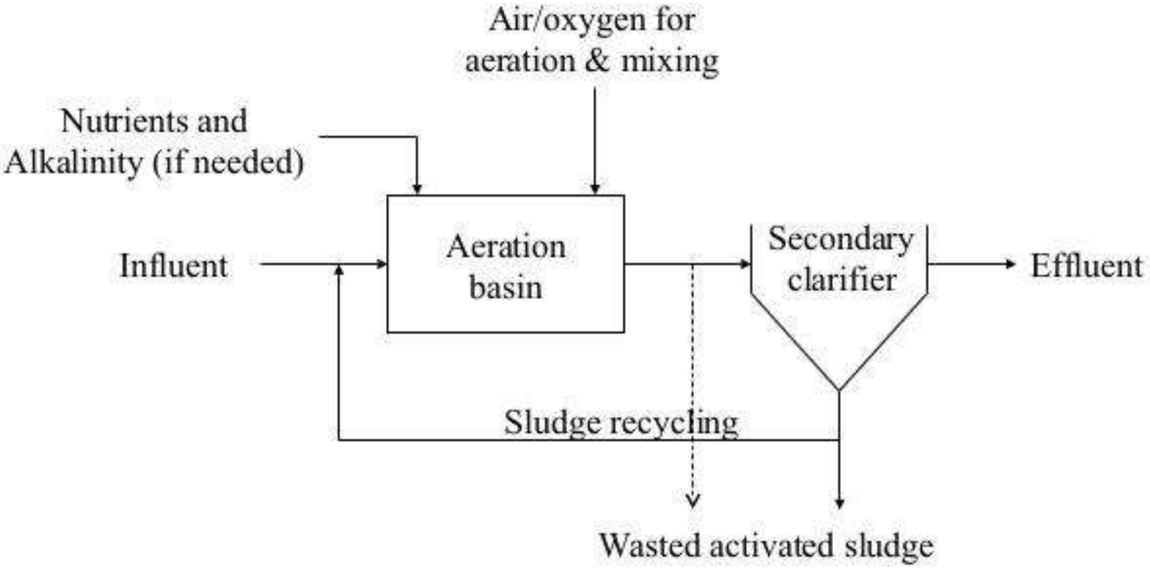
Aeration supplies enough oxygen for aerobic bio-oxidation of organic matter .Mixing keeps biological flocs suspended and ensures contact between wastewater and microorganisms .Two types of aeration/mixing systems: diffused and mechanical aeration systems – Diffused aeration (diffusers, piping and fittings, and blowers) – Mechanical aeration systems - Surface aerators (fixed or floating types) with or without draft tubes - Submerged turbine aerators - Horizontal axis aerators (brush aerators).

Secondary sedimentation tank

To clarify the out-flowing aeration tank contents (mixed liquor) To separate and thicken the biological flocs from mixed liquor for recycling or wasting.

Sludge recycling

Thickened sludge is returned back from secondary clarifier to the aeration tank to maintain desired concentration of biological solids. Includes pumps and necessary piping and fittings.



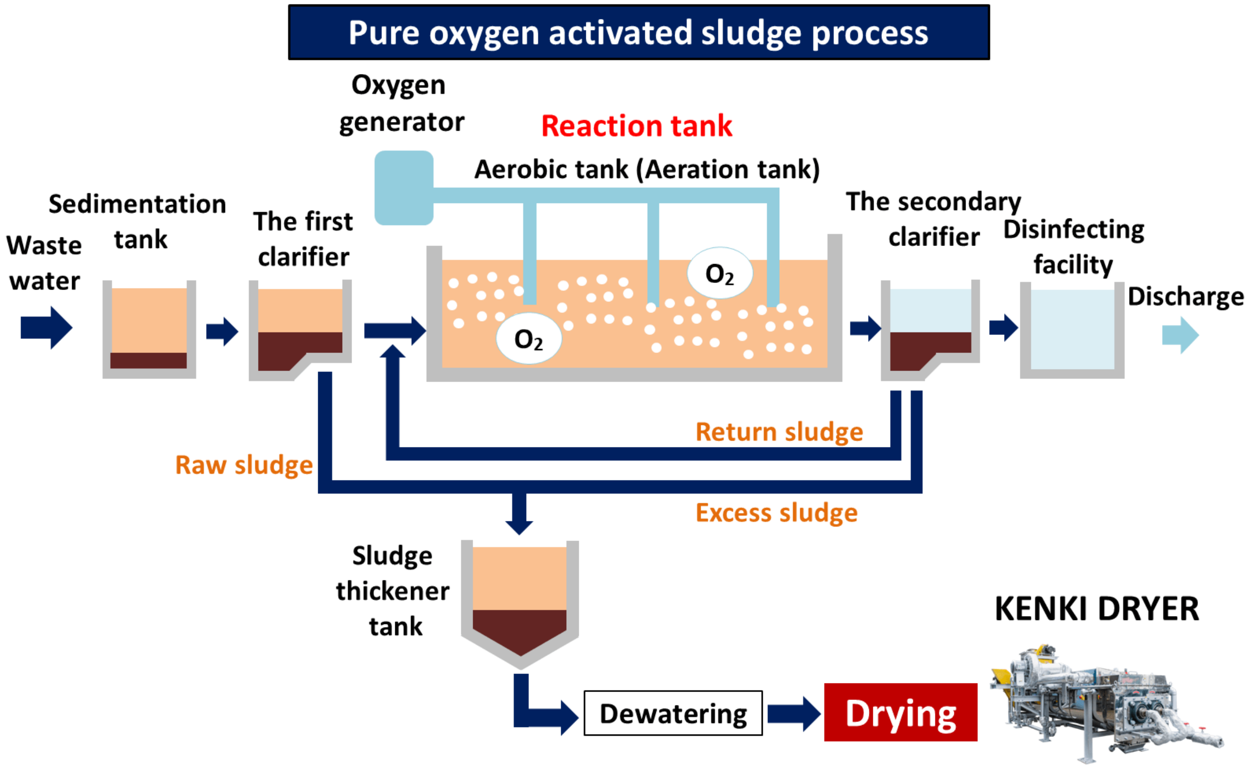
Activated Sludge Process

Activated sludge wasting

Sludge wasting is either as mixed liquor or as thickened sludge

Chemical feed systems

Addition of nutrients and alkalinity may be required if the wastewater is deficient in them – sewage is usually not deficient – Urea and DAP are usually used as nutrients (phosphoric acid or phosphate rock can also be used in place of DAP) – Hydrated lime is dosed for alkalinity



Process

The process involves air or oxygen being introduced into a mixture of primary treated or screened sewage or industrial wastewater combined with organisms to develop a biological floc which reduces the organic content of the sewage. The combination of wastewater and biological mass is commonly known as mixed liquor. In all activated sludge plants, once the wastewater has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant is run off to undergo further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the floc is called return activated sludge (R.A.S.). Excess sludge is called surplus activated sludge (S.A.S.) or waste activated sludge (W.A.S).

S.A.S is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. S.A.S is stored in sludge tanks and is further treated by digestion, either under anaerobic or aerobic conditions prior to disposal.

Mechanisms of Treatment

Aerobic microorganisms (activated sludge), specially bacteria, are responsible. Suspended and colloidal solids of the wastewater becomes integral part of biological sludge through bioflocculation.Biological sludge is constituted of microorganisms, cell debris, and suspended and colloidal solids of the influent

Organic matter of wastewater is bios orbed (adsorbed and absorbed) by microorganisms. Adsorbed organic matter is solubilized through hydrolysis. Simple soluble organic compounds are absorbed by microbes as food. Absorbed organic matter is bio-oxidized (partly respired & rest is used in biological flocs - new microbial biomass - synthesis). Involves biooxidation, biosynthesis and auto oxidation

Advantages of ASP

Diverse; can be used for one household up a huge plant, Removes organics, Oxidation and Nitrification achieved,

Biological nitrification without adding chemicals.

Biological Phosphorus removal.

Solids/ Liquids separation.

Stabilization of sludge.

Capable of removing ~ 97% of suspended solids.

The most widely used wastewater treatment process.

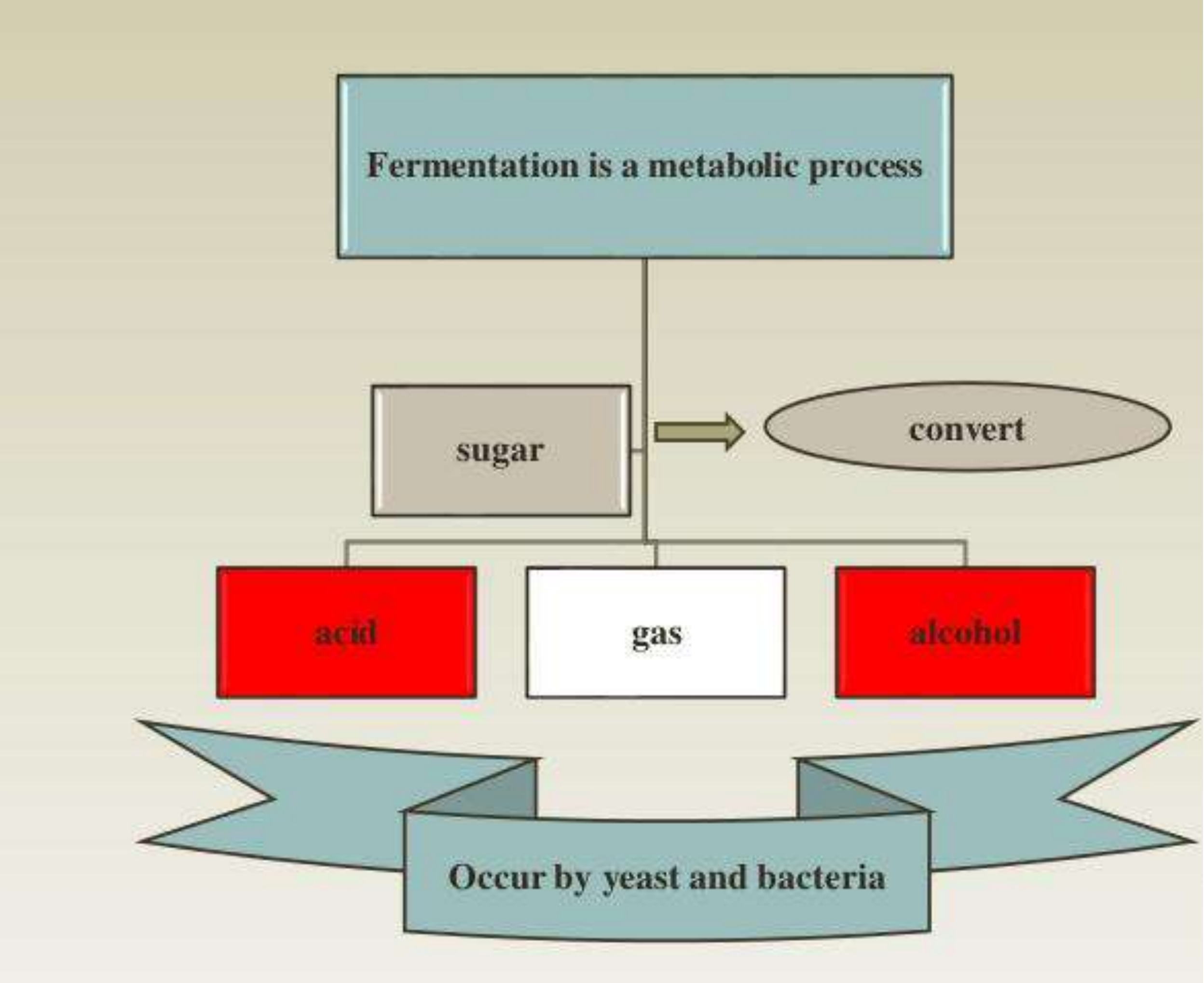
Requires a small land area.

Disadvantages of ASP

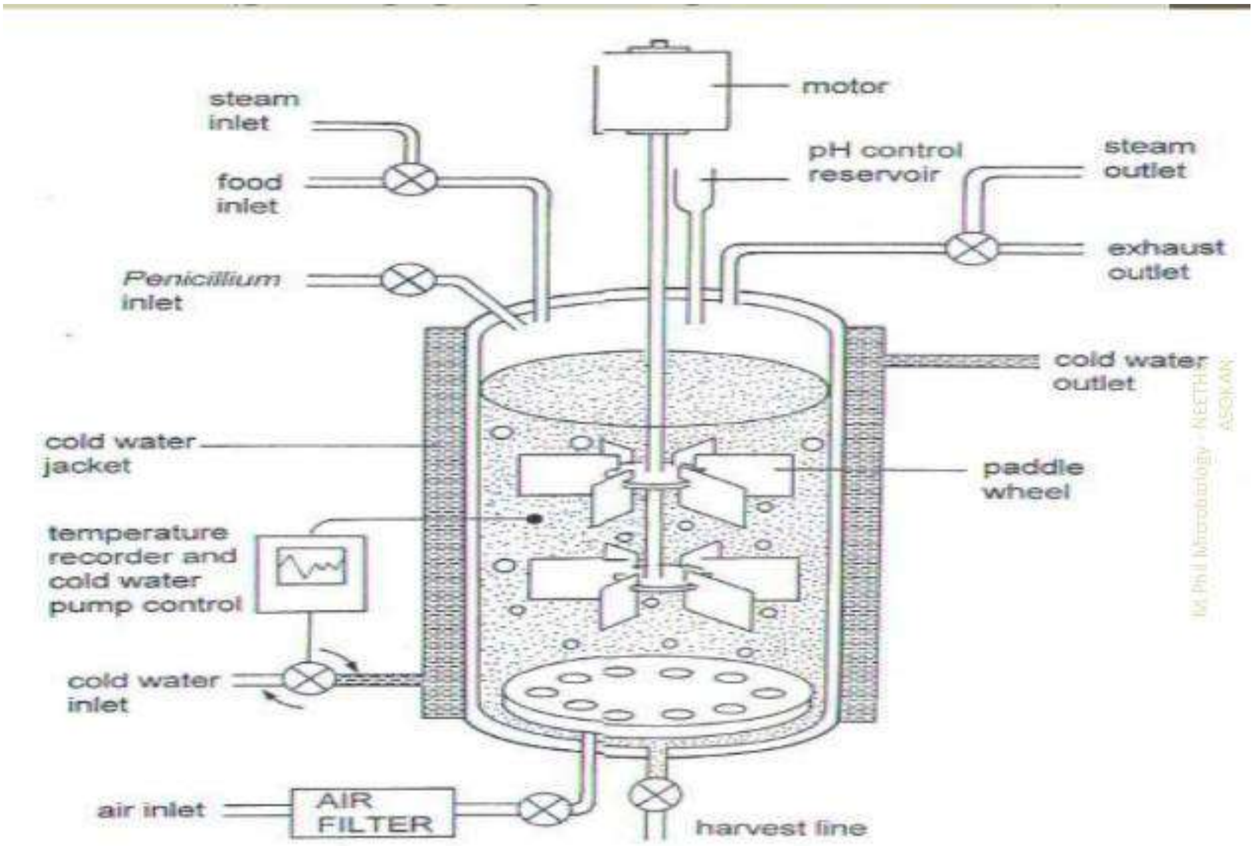
Does not remove color from industrial wastes and may increase the color through formation of highly colored intermediates through oxidation .Does not remove nutrients, tertiary treatment is necessary .Problem of getting well settled sludge .Recycle biomass keeps high biomass concentration in aeration tanks. Detergents possess a major problem. Foam formation takes place

Bio reactors - Downstream processing

Conversion of carbohydrate (e.g. sugar) into acid or alcohol by yeast or bacteria. It is used in brewing and wine making for the Conversion of sugars to alcohol (ethanol – CH_3CH_2OH)This process, followed by distillation, can be used to obtain pure ethanol (bioethanol) for use as a transport biofuel It can also be viewed as the energy-yielding anaerobic metabolic breakdown (respiration) of a nutrient molecule such as glucose, without net oxidation (eg., in muscle cells) Fermentation typically refers to the fermentation of sugar to alcohol using yeast, but other fermentation processes include making of yogurt, souring of milk, rising of dough. Conversion of carbohydrate (eg. sugar) to acid/alcohol by yeast/bacteria.



Structure of Fermenter



Three stages

Upstream process, Fermentation process, downstream process

Upstream Process

Upstream processing includes. Formulation of the fermentation medium, sterilization of air, fermentation medium and the Fermenter, inoculum preparation and inoculation of the fermentation medium should contain an energy source, a carbon source, a nitrogen source and micronutrients required for the growth of the microorganism along with water and oxygen, if necessary.

A medium which is used for a large scale fermentation, in order to ensure the sustainability of the operation, should have the following characteristics; It should be cheap and easily available. It should maximize the growth of the microorganism, productivity and the rate of formation of the desired product .It should minimize the formation of undesired products.

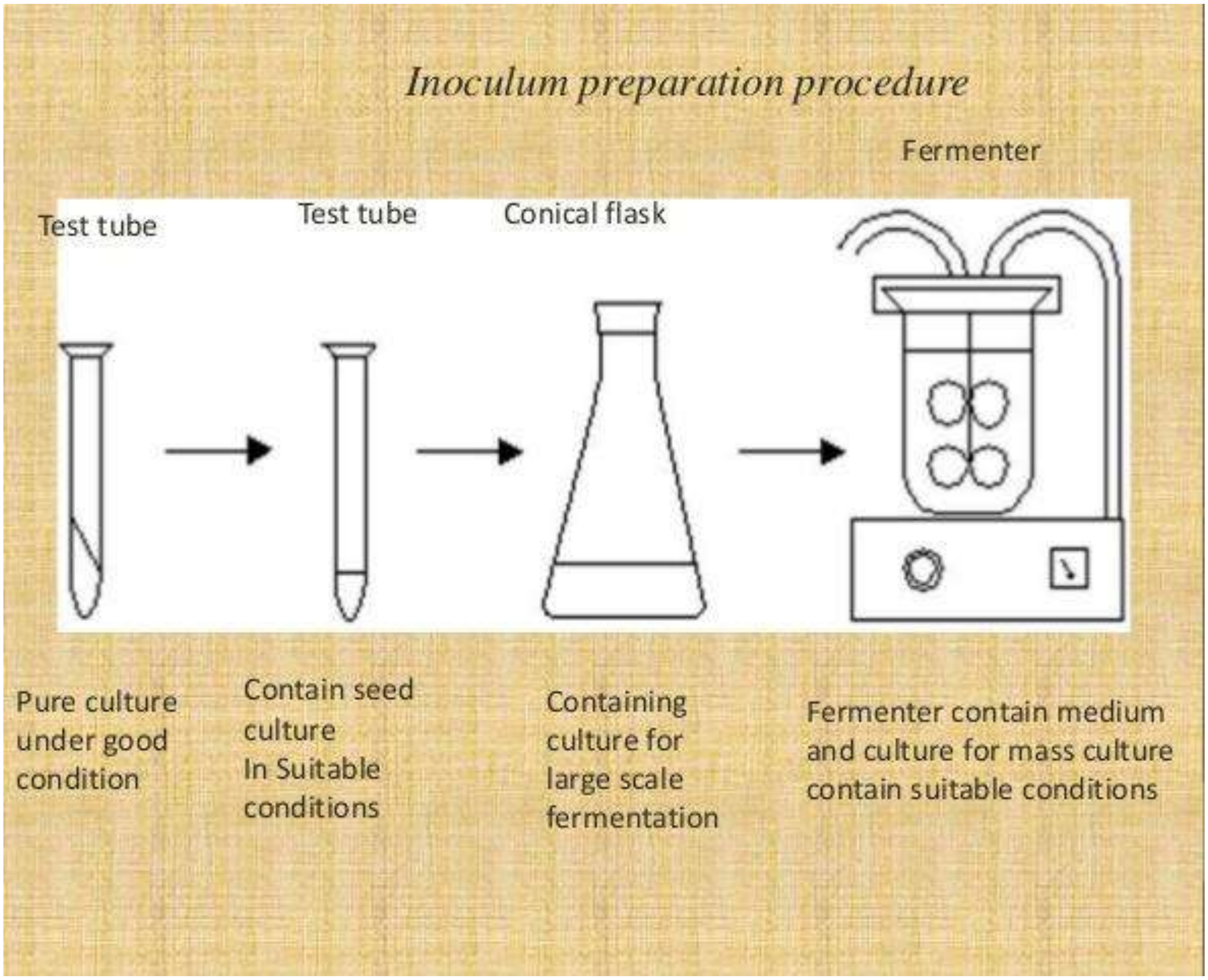
Usually, waste products from other industrial processes, such as molasses, lignocelluloses wastes, cheese whey and corn steep liquor, after modifying with the incorporation of additional nutrients, are used as the substrate for many industrial fermentations. Sterilisation is essential for preventing the contamination with any undesired microorganisms. Air is sterilised by membrane filtration while the medium is usually heat sterilised. Any nutrient component which is heat labile is filter-sterilised and later added to the sterilised medium. The fermenter may be sterilised together with the medium or separately. Inoculum build up is the preparation of the seed culture in amounts sufficient to be used in the large Fermenter vessel. This involves growing the microorganisms obtained from the pure stock culture in several consecutive Fermenter. This process cuts down the time required for the growth of microorganisms in the Fermenter, thereby increasing the rate of productivity. Then the seed culture obtained through this process is used to inoculate the fermentation medium.

Three cultural fermentation system used in bioreactors

Batch culture fermentation

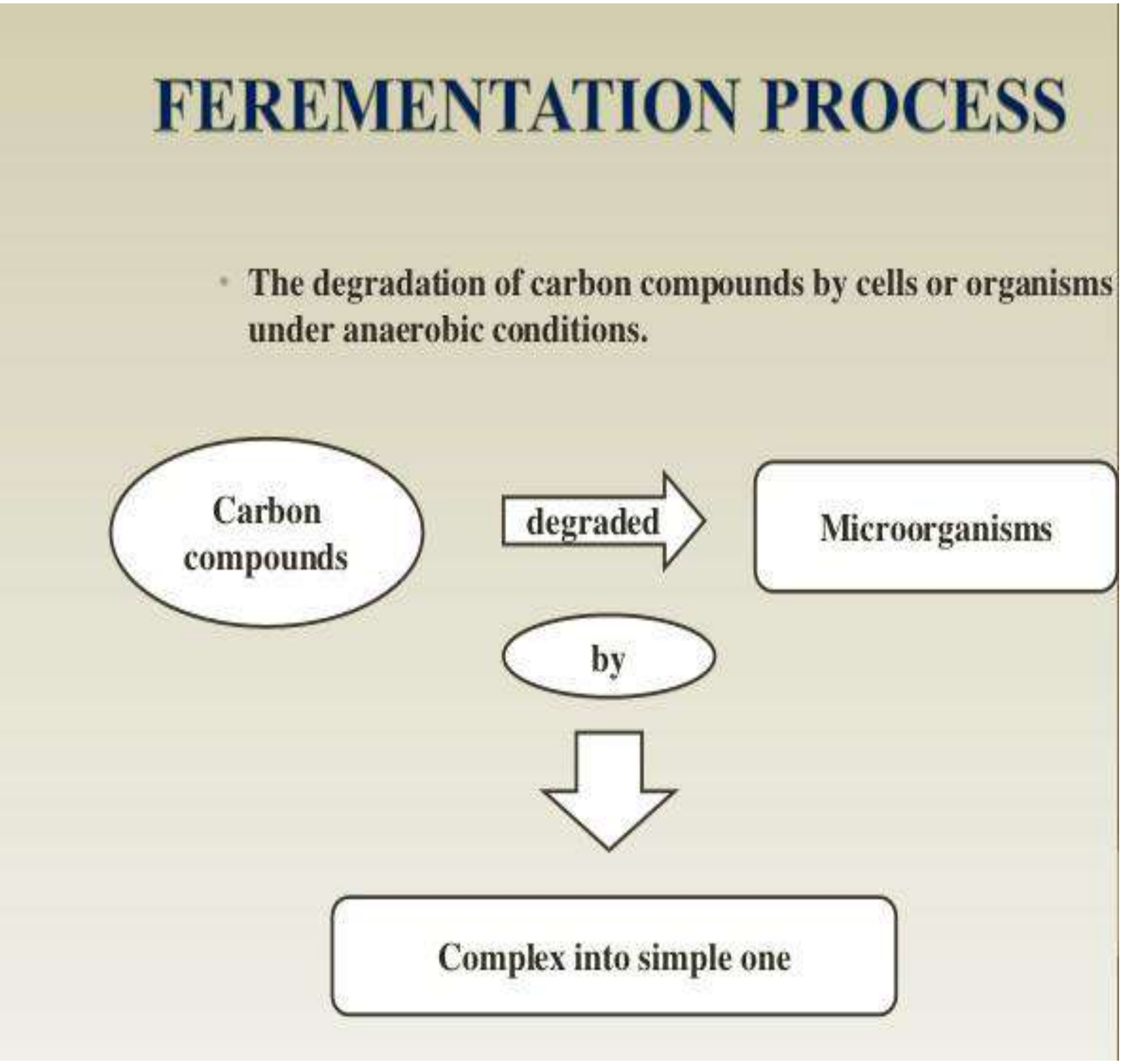
Continuous culture fermentation

Feed batch culture fermentation



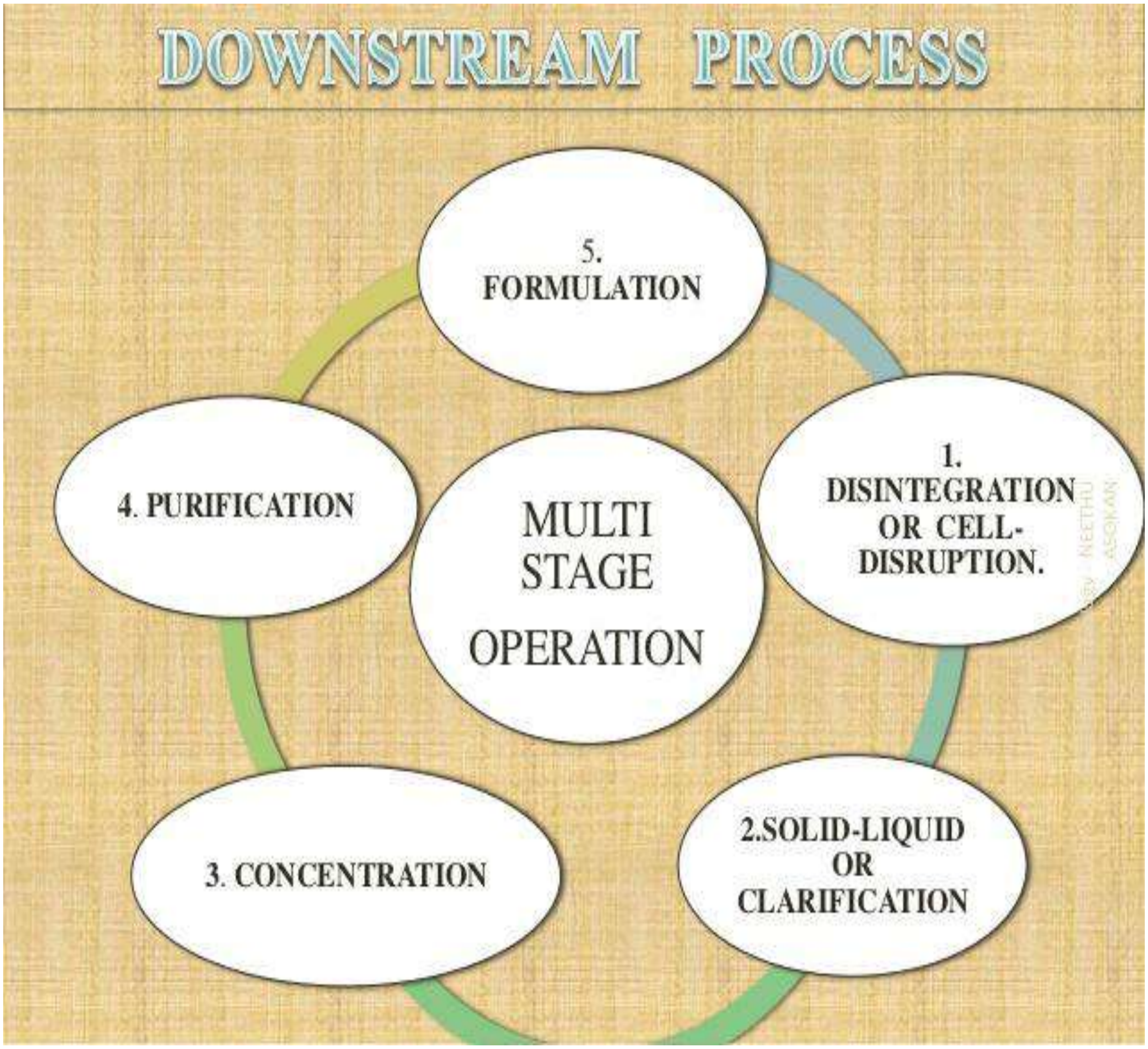
Downstream Process

When fermentation is over, the desired product is recovered from the growth medium. Then the product is Extraction Purification and Packed of a biotechnological product from fermentation is referred to as DSP or product recovery or downstream processing. The end products include Antibiotics, Amino acid, Vitamins, Organic acid, Industrial enzyme, vaccines etc. It is complex and important as fermentation process.



FEREMENTATION PROCESS

- The degradation of carbon compounds by cells or organisms under anaerobic conditions.



DOWNSTREAM PROCESS

MULTI
STAGE
OPERATION

1. DISINTEGRATION OR CELL-DISRUPTION.

2.SOLID-LIQUID OR CLARIFICATION

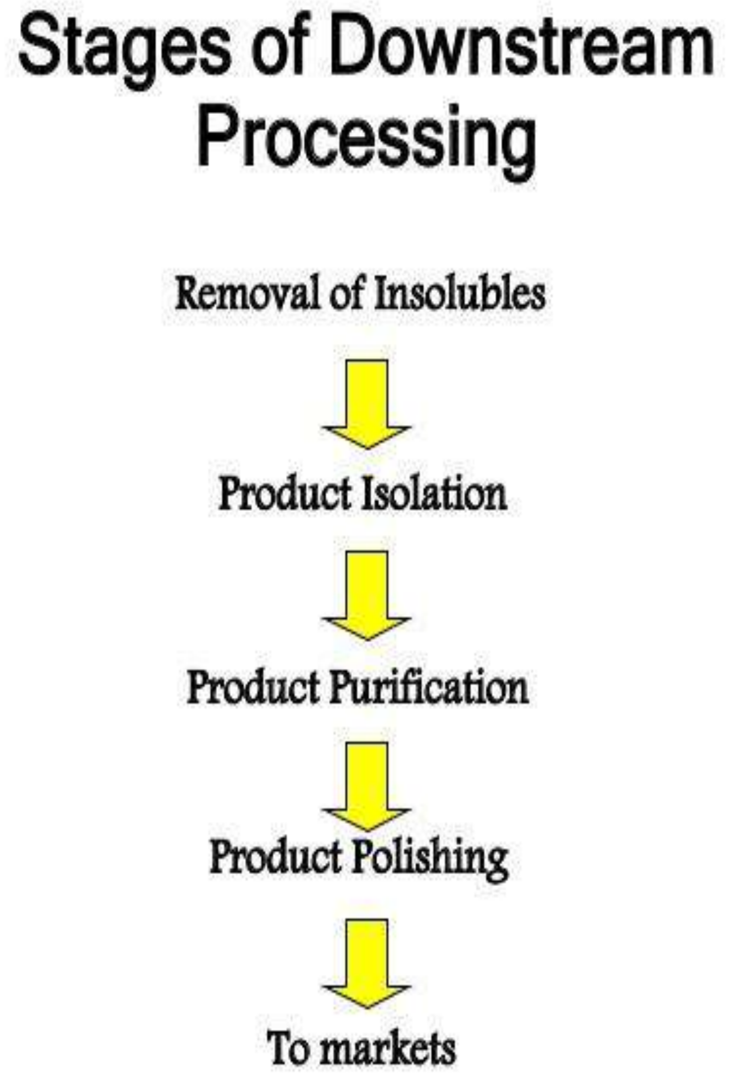
3. CONCENTRATION

4. PURIFICATION

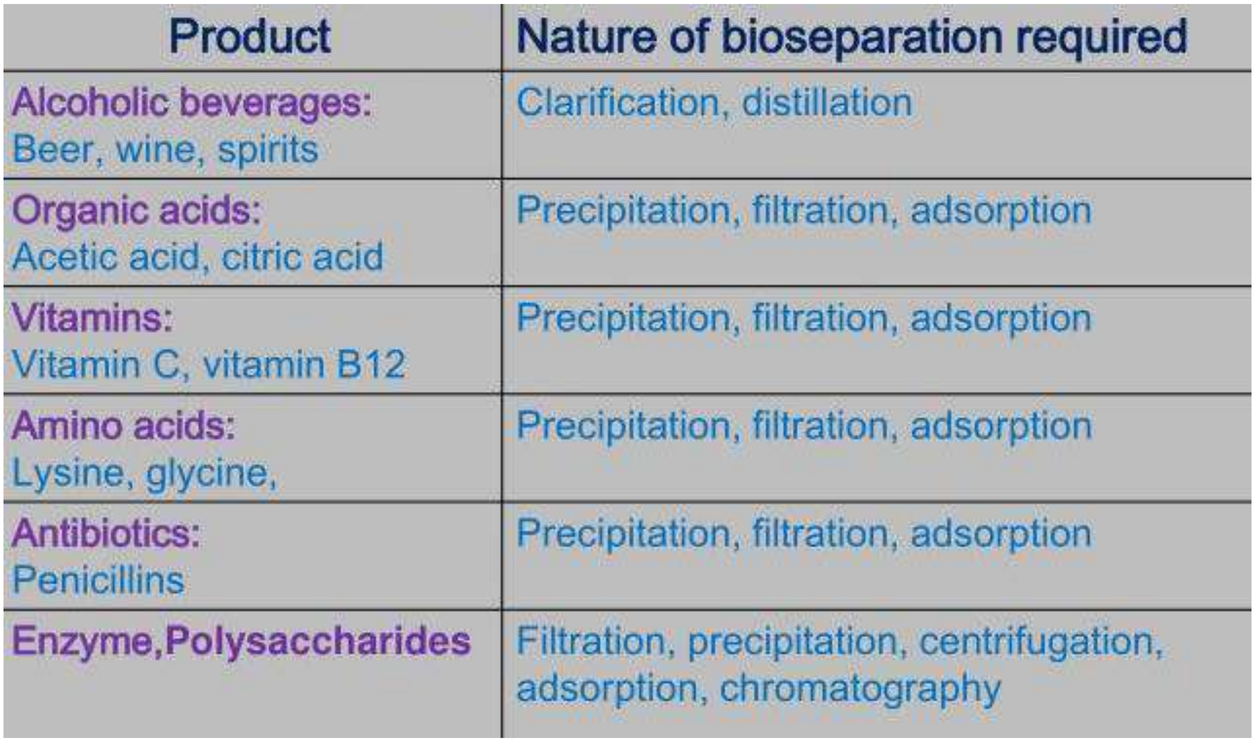
5. FORMULATION

Downstream processing

The various stages of processing that occur after the completion of the fermentation or bioconversion stage, including separation, purification, and packaging of the product

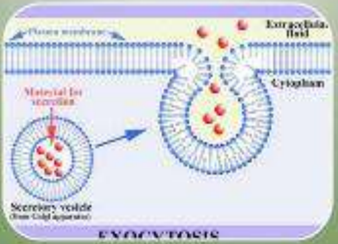


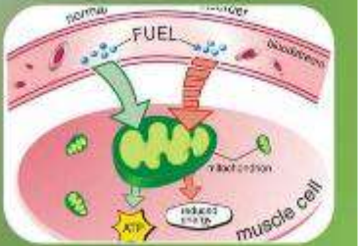
Biological Products



Product	Nature of bioseparation required
Alcoholic beverages: Beer, wine, spirits	Clarification, distillation
Organic acids: Acetic acid, citric acid	Precipitation, filtration, adsorption
Vitamins: Vitamin C, vitamin B12	Precipitation, filtration, adsorption
Amino acids: Lysine, glycine,	Precipitation, filtration, adsorption
Antibiotics: Penicillins	Precipitation, filtration, adsorption
Enzyme,Polysaccharides	Filtration, precipitation, centrifugation, adsorption, chromatography

WHAT ARE THE CLASSES OF PRODUCT OBTAINED???





Cell itself

- Bakers yeast
- Bio-fertilizers

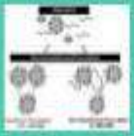
Extracellular type

- Antibiotics
- Alcohol

Intracellular type

- Enzymes
- Vitamins

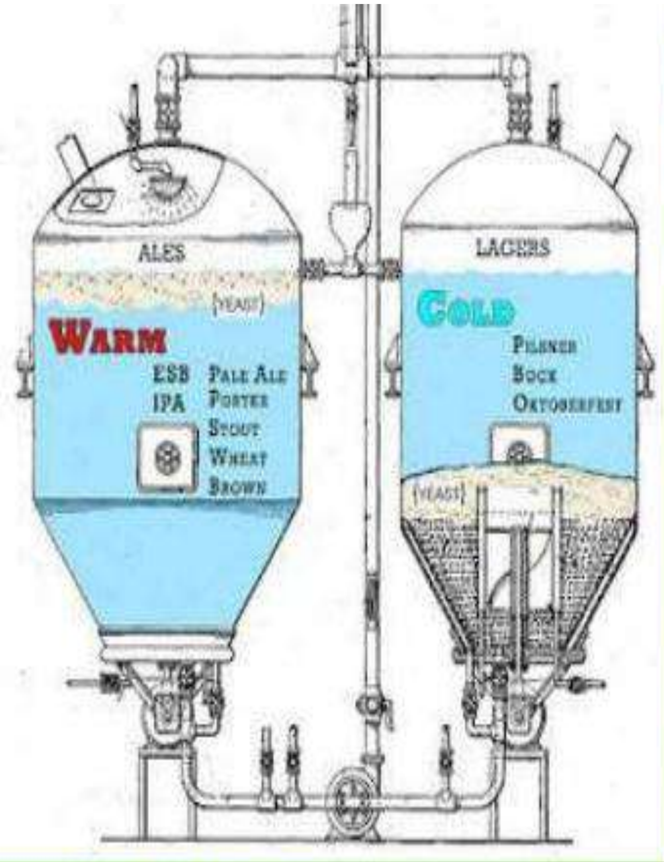
IF THE PRODUCT IS THE CELL ITSELF ???



Separation of particles

- Filtration
- Centrifugation
- Flocculation and floatation

Cooling and packaging


ALES
(YEAST)
WARM
ESB
PALE ALE
IPA
PORTER
STOUT
WHEAT
BROWN
LAGERS
COLD
PILSNER
BOCK
OKTOBERFEST
(YEAST)

IF THE PRODUCT IS EXCRETED OUTSIDE THE CELL ??

Separation of Particles

- Centrifugation or filtration
- Flocculation and floatation

Extraction

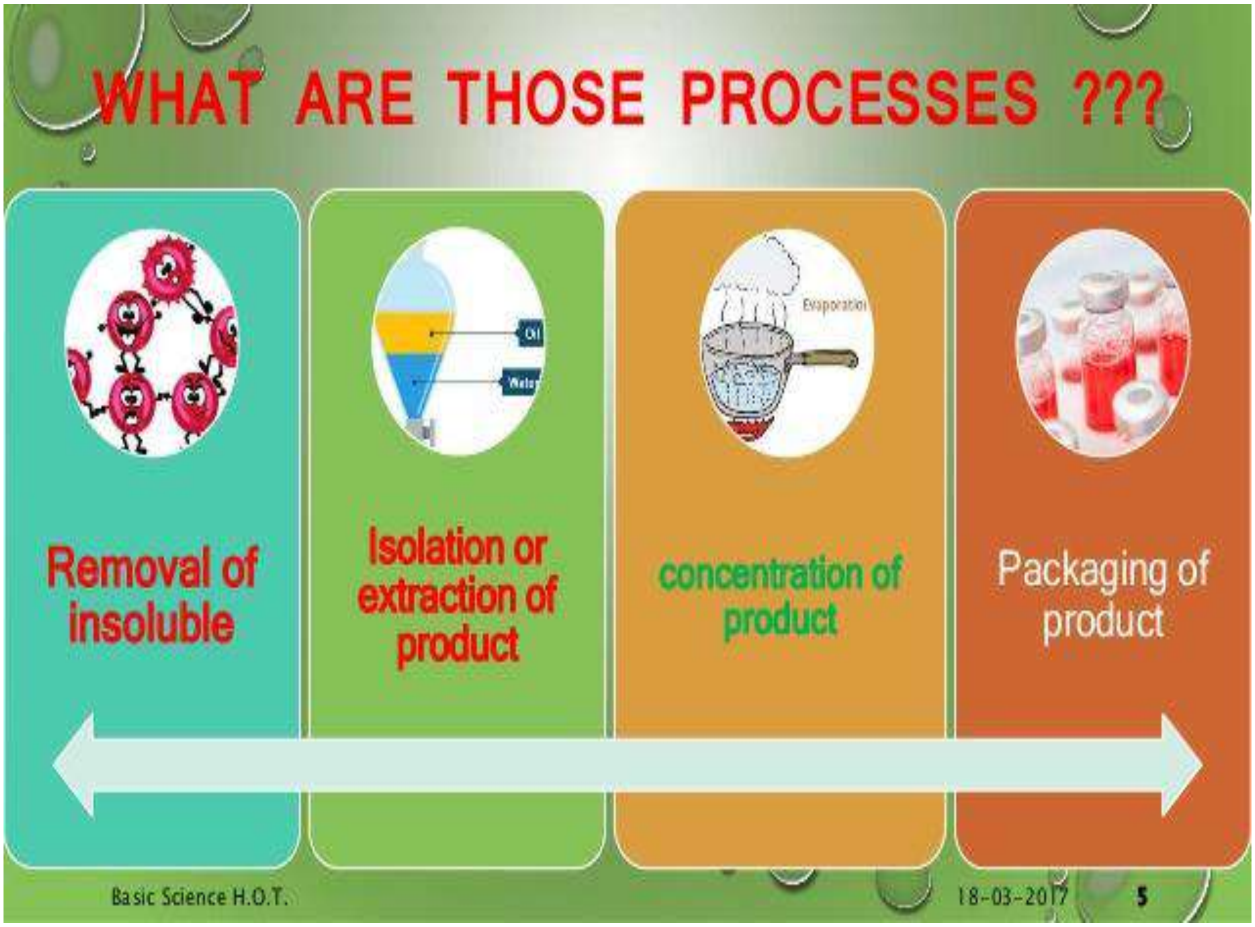
- Liquid-liquid extraction
- Whole broth extraction
- Aqueous Multiphase Extraction

Concentration

- Chromatographic techniques
- Evaporation process
- Crystallization
- Adsorption

Unit operations in downstream processing

Cell Separation	Cell disruption	Clarification	Concentration	High resolution techniques	Finishing/packaging
Flocculation	Homogenizers	Centrifugation	Precipitation	Chromatography	Crystallization
Centrifugation	Hydrolytic enzymes	Filtration	Chromatography	Electrophoresis	Filtration
Filtration			Ultrafiltration	Dialysis	Gel chromatography
			Partitioning		Drying
			Distillation		

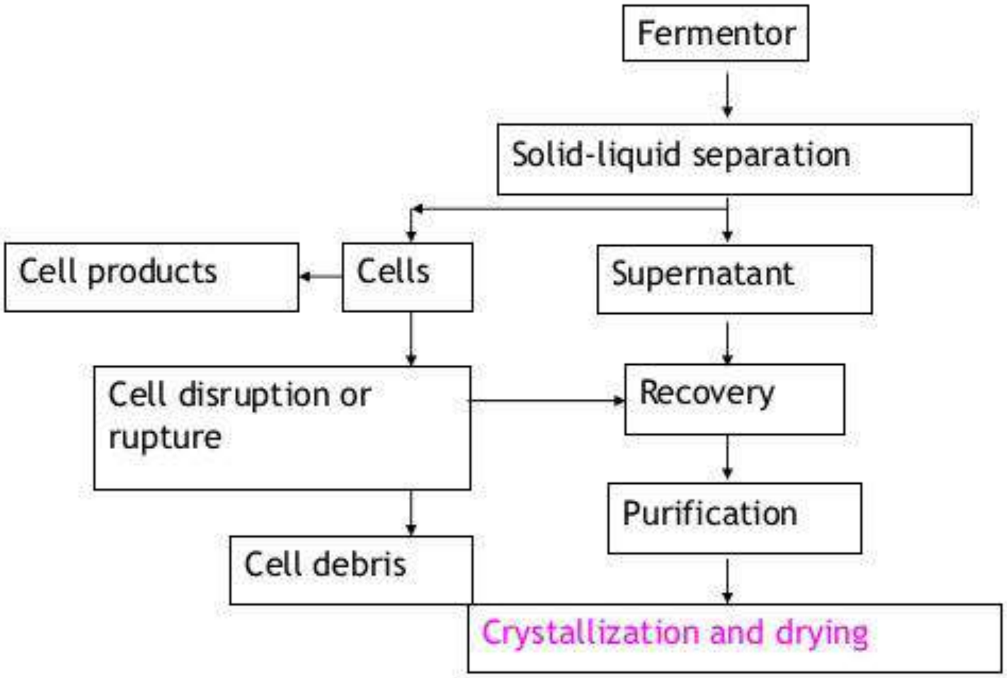


WHAT ARE THOSE PROCESSES ???

- Removal of insoluble
- Isolation or extraction of product
- concentration of product
- Packaging of product

Recovery and Purification of Bio-Products

- Strategies to recovery and purify bio-products


Fermentor

Solid-liquid separation

Cells

Supernatant

Cell products

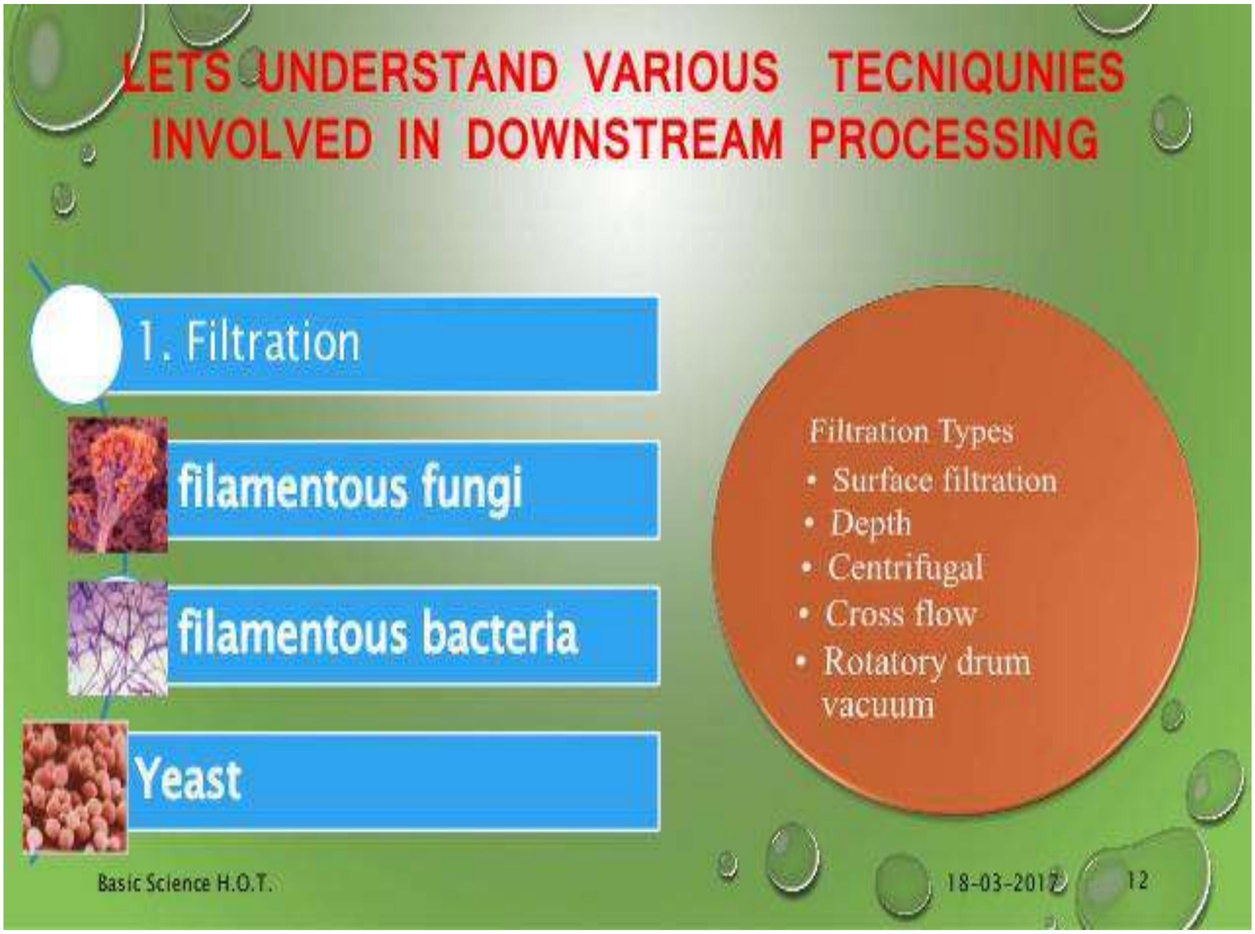
Cell disruption or rupture

Recovery

Purification

Cell debris

Crystallization and drying



LETS UNDERSTAND VARIOUS TECNIQUNIES INVOLVED IN DOWNSTREAM PROCESSING

1. Filtration

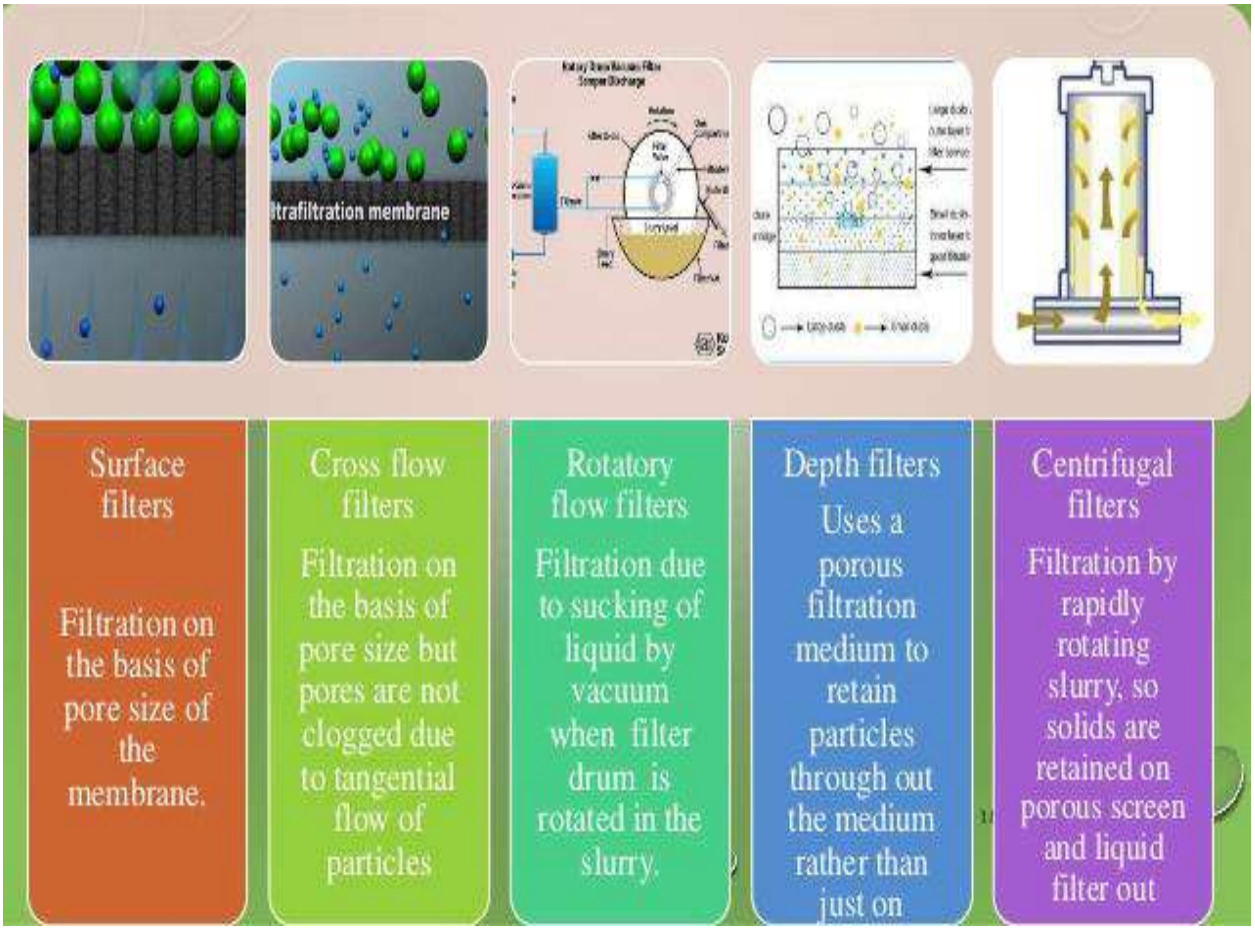
filamentous fungi

filamentous bacteria

Yeast

Filtration Types

- Surface filtration
- Depth
- Centrifugal
- Cross flow
- Rotatory drum vacuum



Surface filters

Filtration on the basis of pore size of the membrane.

Cross flow filters

Filtration on the basis of pore size but pores are not clogged due to tangential flow of particles

Rotatory flow filters

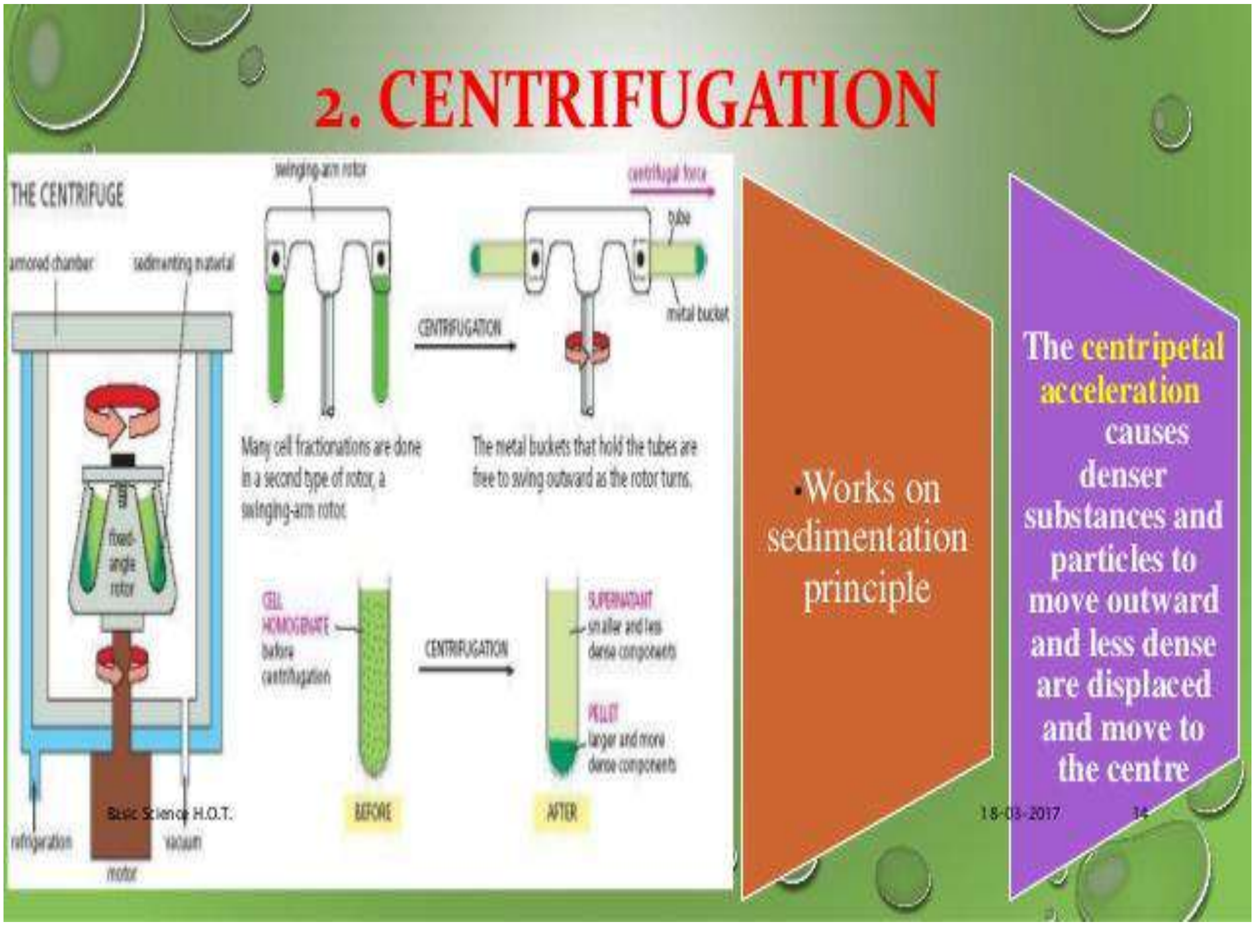
Filtration due to sucking of liquid by vacuum when filter drum is rotated in the slurry.

Depth filters

Uses a porous filtration medium to retain particles through out the medium rather than just on

Centrifugal filters

Filtration by rapidly rotating slurry, so solids are retained on porous screen and liquid filter out



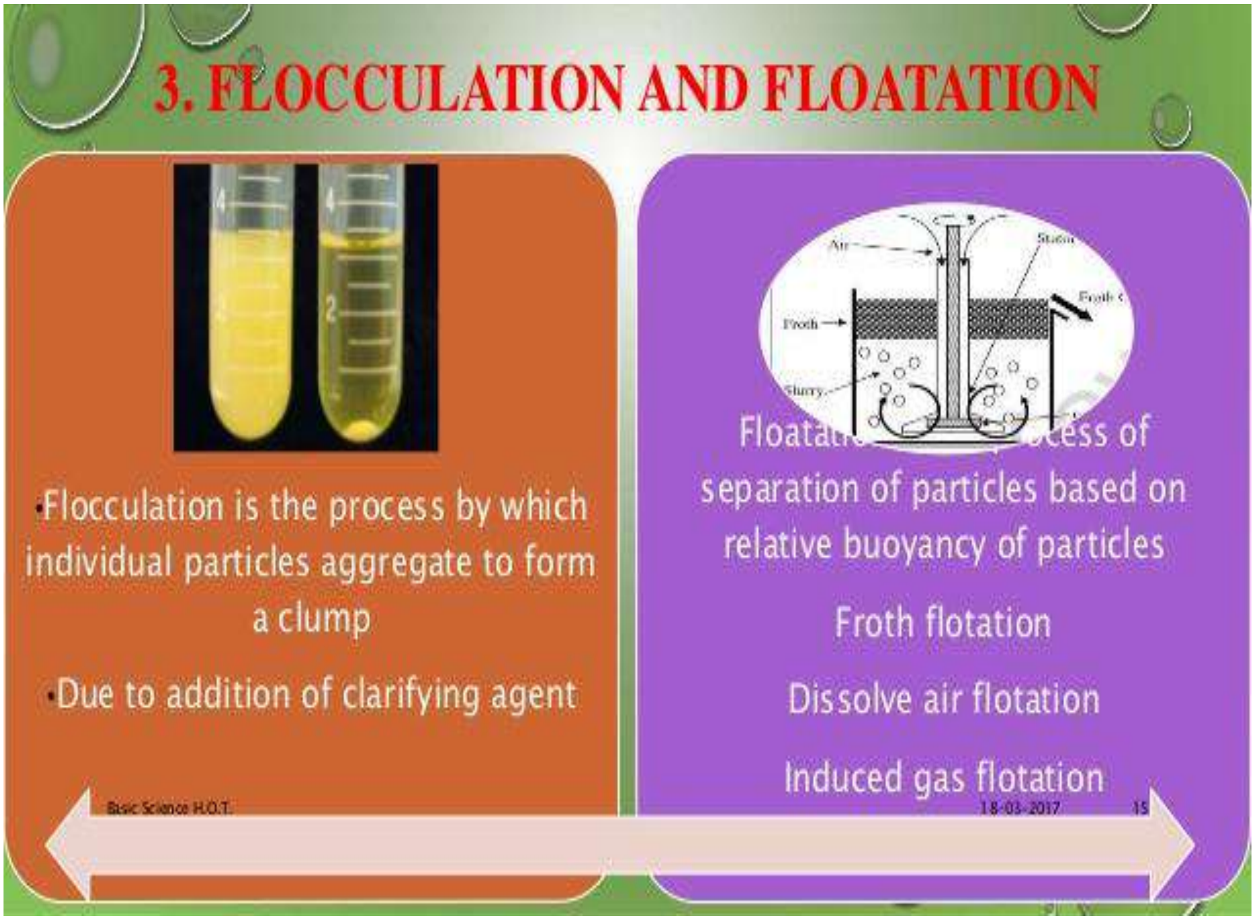
2. CENTRIFUGATION

Many cell fractionations are done in a second type of rotor, a swinging-arm rotor.

The metal buckets that hold the tubes are free to swing outward as the rotor turns.

- Works on sedimentation principle

The centripetal acceleration causes denser substances and particles to move outward and less dense are displaced and move to the centre



3. FLOCCULATION AND FLOATATION

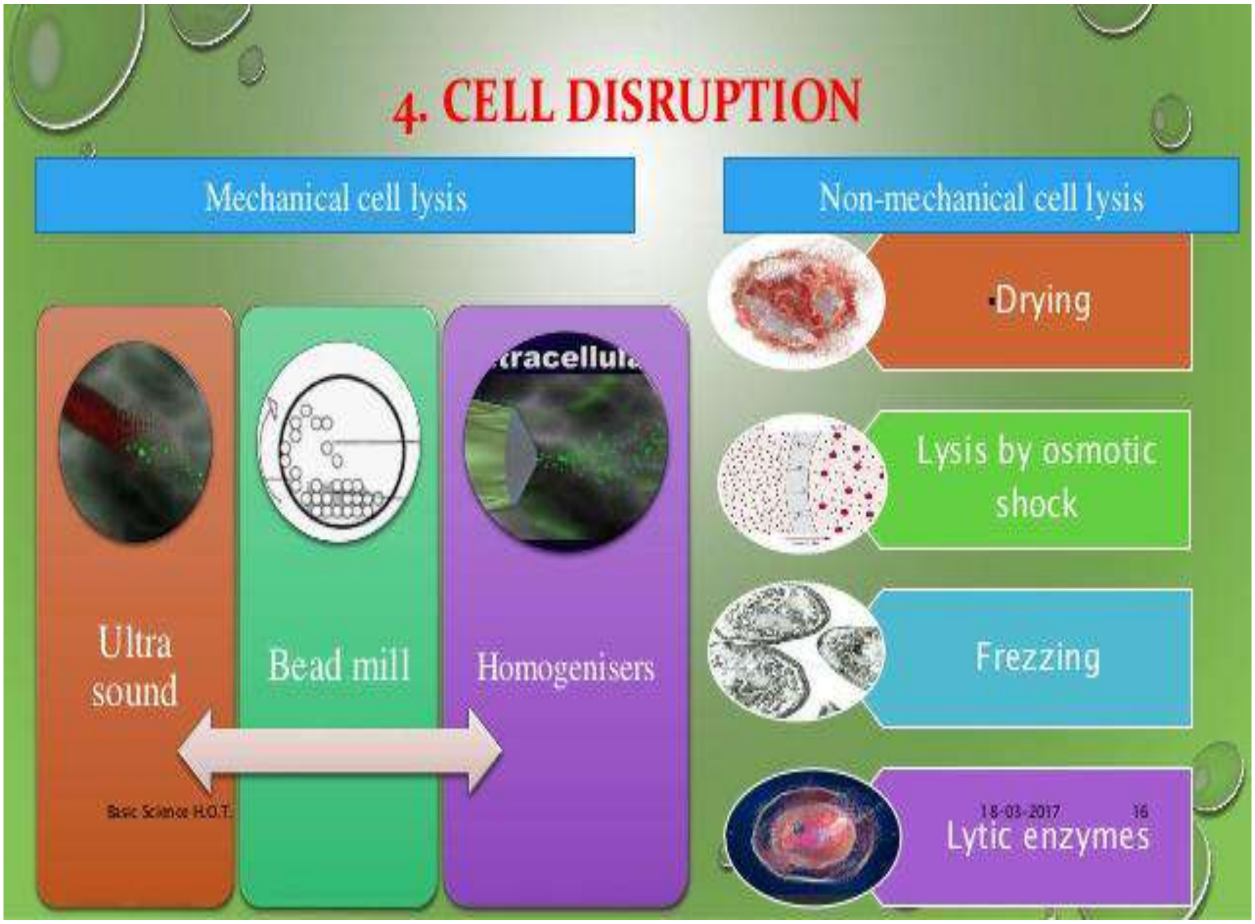
- Flocculation is the process by which individual particles aggregate to form a clump
- Due to addition of clarifying agent

Floata [illegible] ocess of separation of particles based on relative buoyancy of particles

Froth flotation

Dissolve air flotation

Induced gas flotation



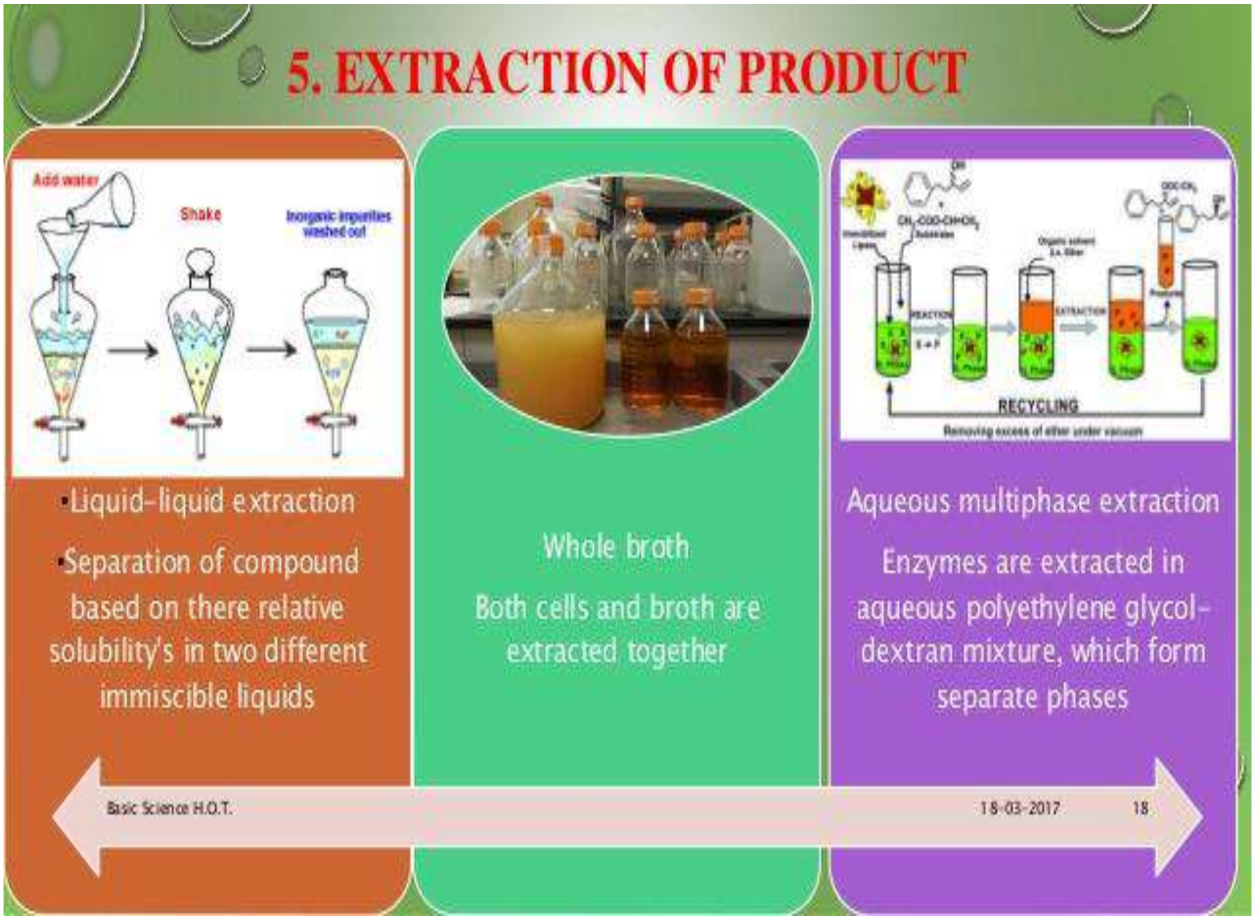
4. CELL DISRUPTION

Mechanical cell lysis

- Ultra sound
- Bead mill
- Homogenisers

Non-mechanical cell lysis

- Drying
- Lysis by osmotic shock
- Frezzing
- Lytic enzymes



5. EXTRACTION OF PRODUCT

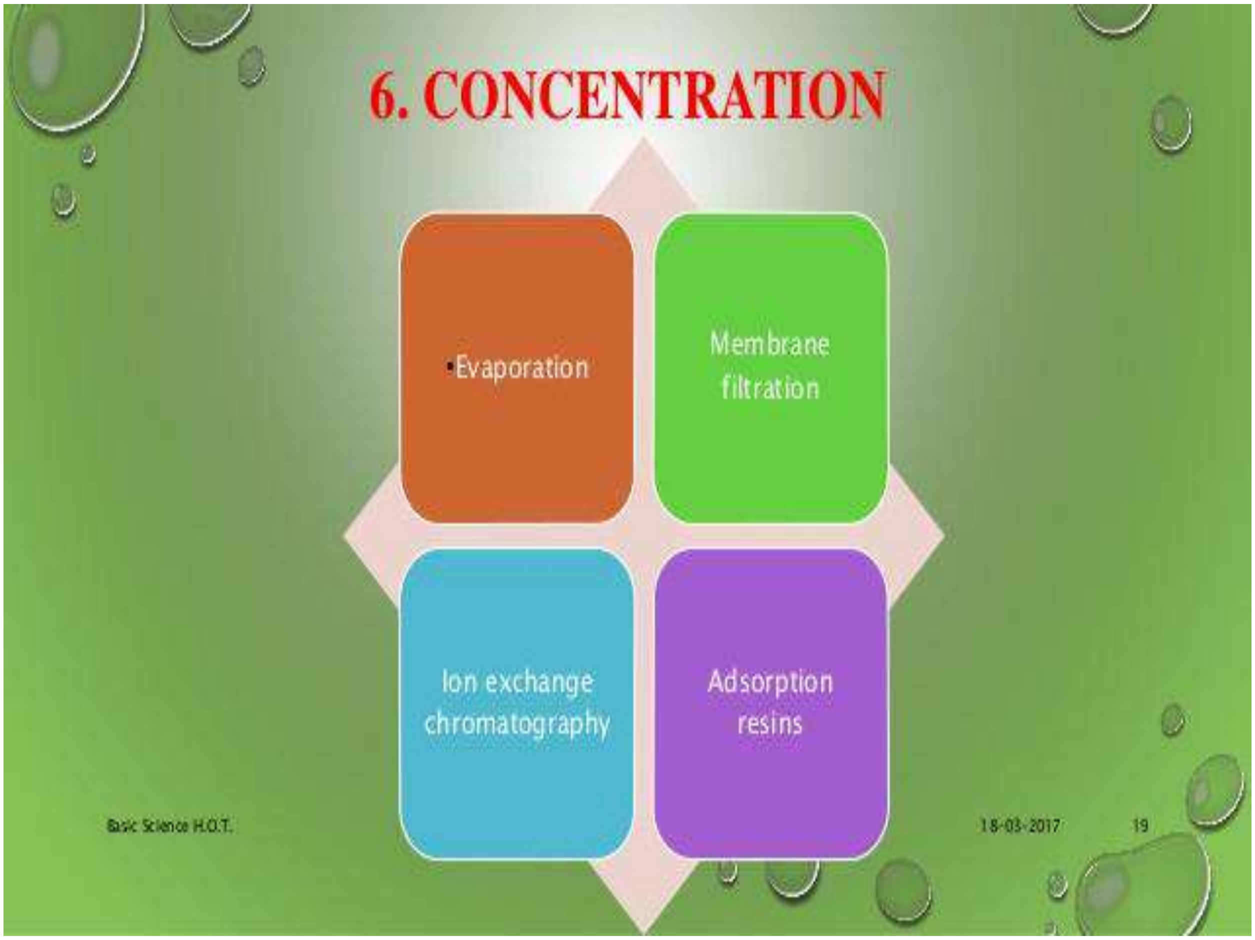
- Liquid-liquid extraction
- Separation of compound based on there relative solubility's in two different immiscible liquids

Whole broth

Both cells and broth are extracted together

Aqueous multiphase extraction

Enzymes are extracted in aqueous polyethylene glycol-dextran mixture, which form separate phases



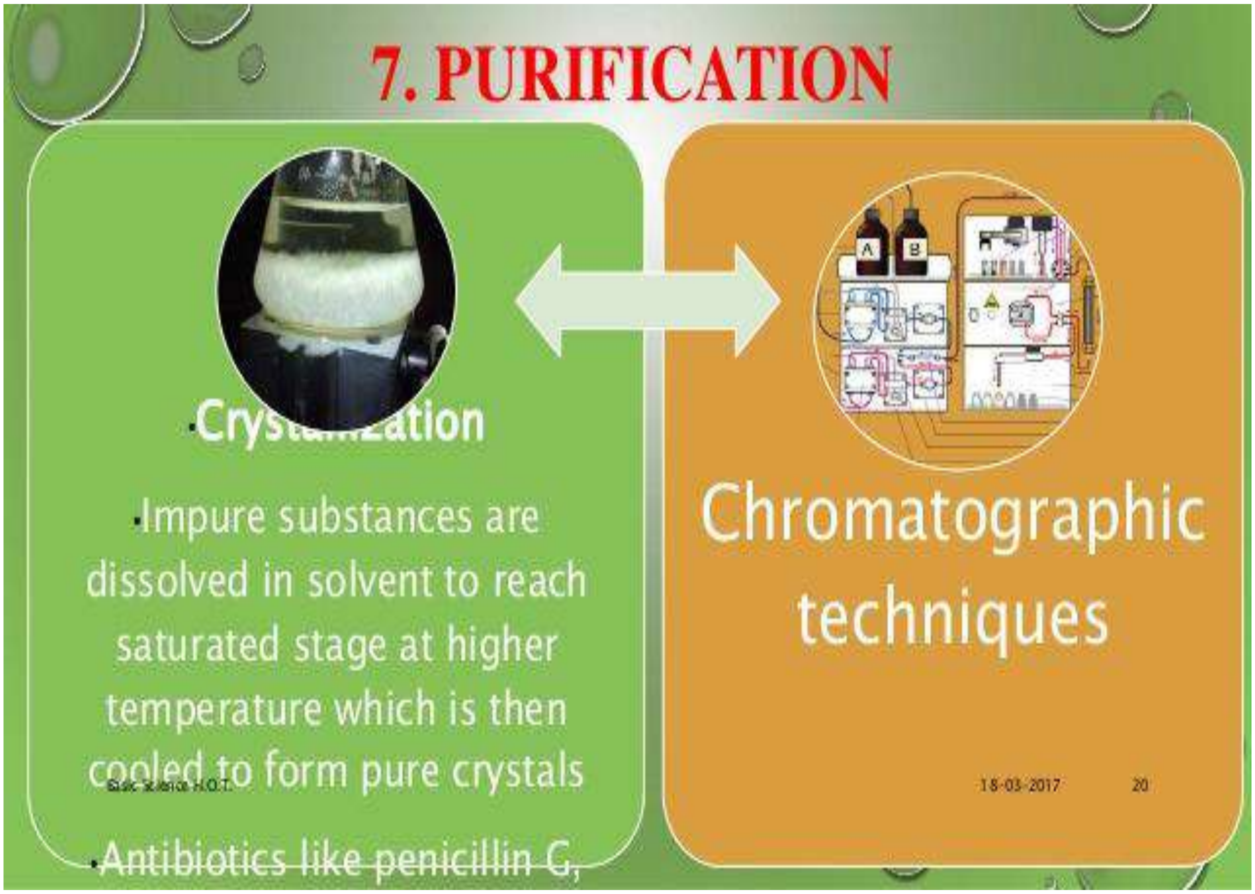
6. CONCENTRATION

- Evaporation

Membrane filtration

Ion exchange chromatography

Adsorption resins



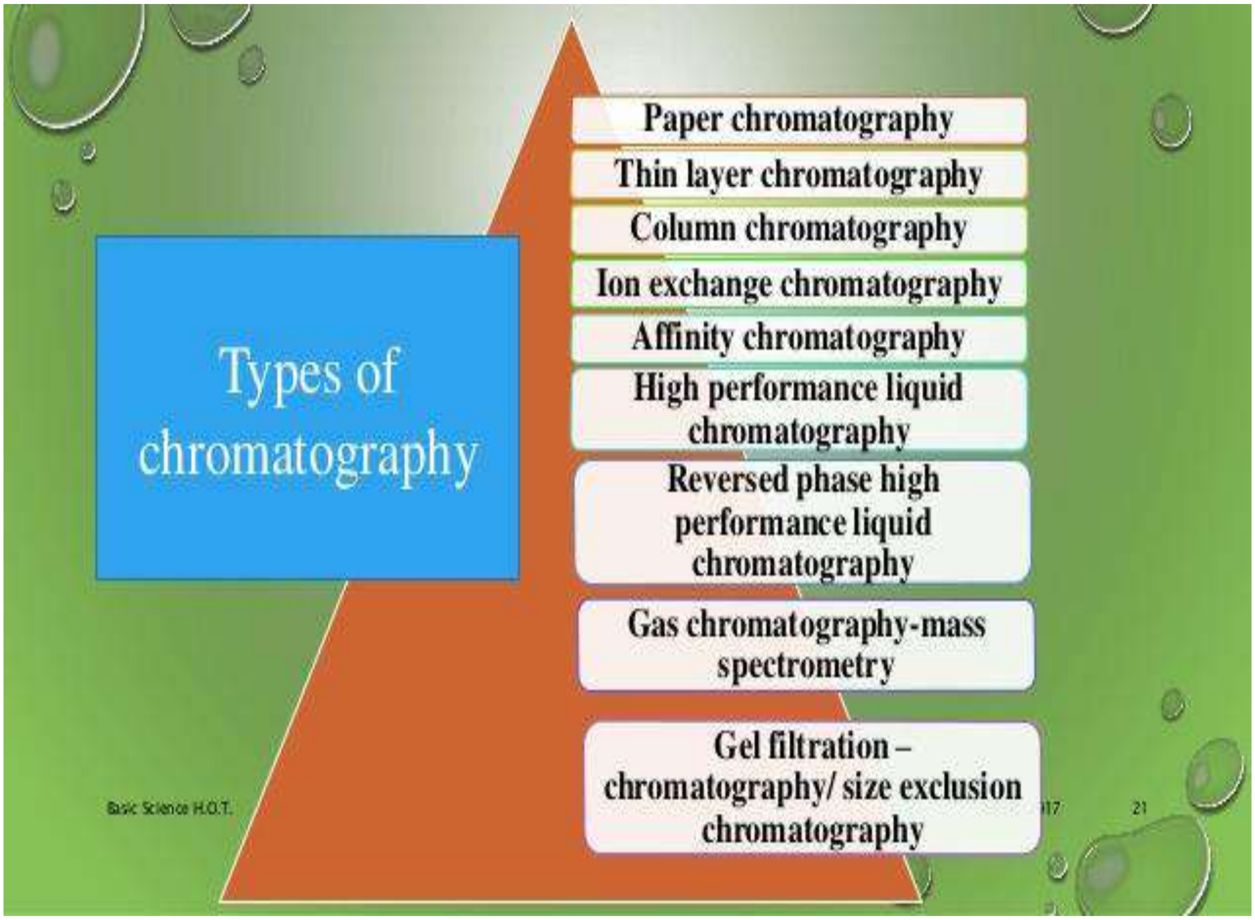
7. PURIFICATION

- Crystallization

- Impure substances are dissolved in solvent to reach saturated stage at higher temperature which is then cooled to form pure crystals

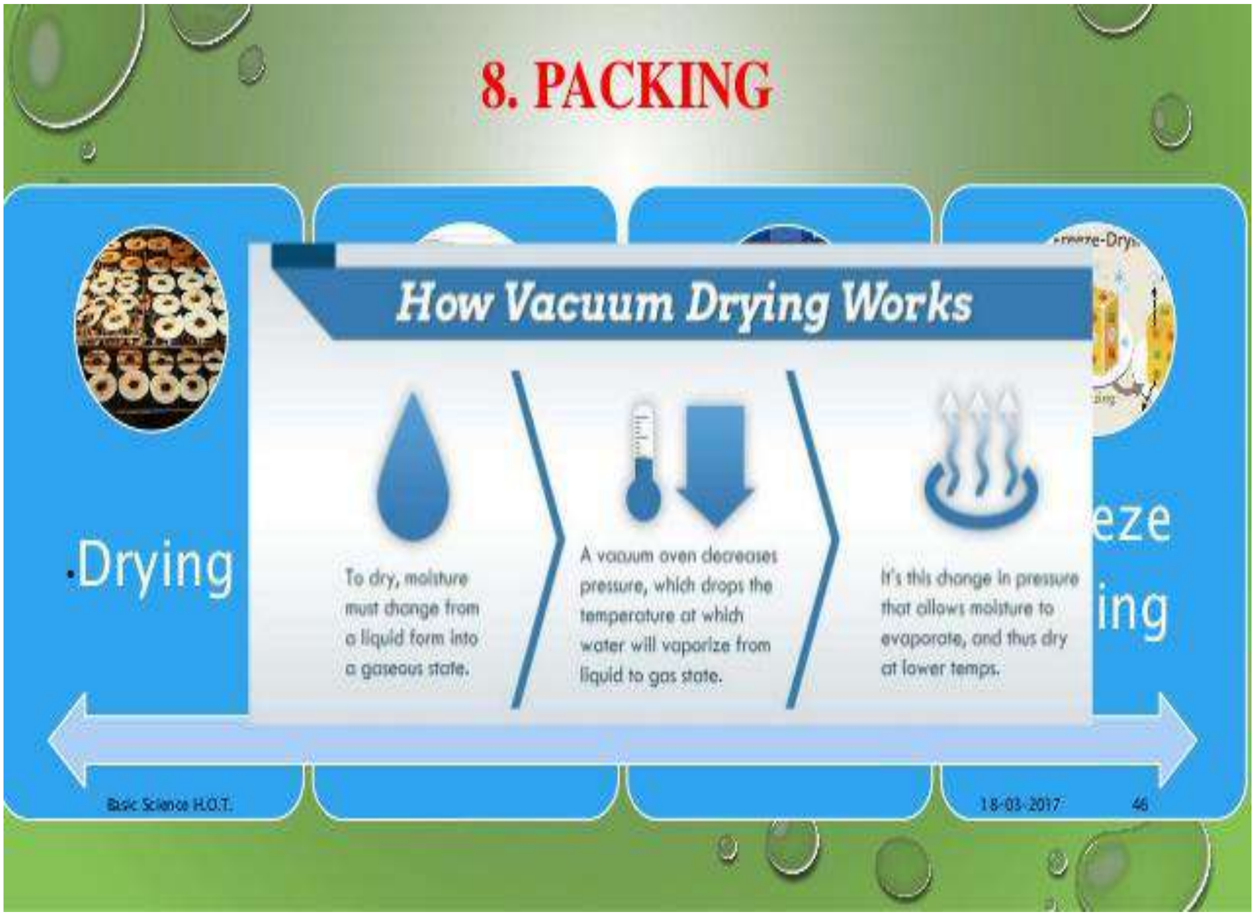
- Antibiotics like penicillin G,

Chromatographic techniques



Types of chromatography

- Paper chromatography
- Thin layer chromatography
- Column chromatography
- Ion exchange chromatography
- Affinity chromatography
- High performance liquid chromatography
- Reversed phase high performance liquid chromatography
- Gas chromatography-mass spectrometry
- Gel filtration – chromatography/ size exclusion chromatography



8. PACKING

Drying

How Vacuum Drying Works

To dry, moisture must change from a liquid form into a gaseous state.

A vacuum oven decreases pressure, which drops the temperature at which water will vaporize from liquid to gas state.

It's this change in pressure that allows moisture to evaporate, and thus dry at lower temps.

Basic Science H.O.T.

18-03-2017

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Fermentation - Down Stream Processing

Five stages in downstream processing after Fermentation

1. Solid-Liquid Separation
2. Release of Intracellular Products
3. Concentration
4. Purification by Chromatography and
5. Formulation.

Stage 1: Solid-Liquid Separation

The first step in product recovery is the separation of whole cells (cell biomass) and other insoluble ingredients from the culture broth (Note: If the desired product is an intracellular metabolite, it must be released from the cells before subjecting to solid-liquid separation).Some authors use the term harvesting of microbial cells for the separation of cells from the culture medium.

i). Depth Filters:

They are composed of a filamentous matrix such as glass wool, asbestos or filter paper. The particles are trapped within the matrix and the fluid passes out. Filamentous fungi can be removed by using depth filters.

ii). Absolute Filters:

These filters are with specific pore sizes that are smaller than the particles to be removed. Bacteria from culture medium can be removed by absolute filters.

iii). Rotary Drum Vacuum Filters:

These filters are frequently used for separation of broth containing 10-40% solids (by volume) and particles in the size of 0.5-10μm. Rotary drum vacuum filters have been successfully used for filtration of yeast cells and filamentous fungi. The equipment is simple with low power consumption and is easy to operate. The filtration unit consists of a rotating drum partially immersed in a tank of broth (Fig. 20.2). As the drum rotates, it picks up the biomass which gets deposited as a cake on the drum surface. This filter cake can be easily removed.

iv) Membrane Filters:

In this type of filtration, membranes with specific pore sizes can be used. However, clogging of filters is a major limitation. There are two types of membrane filtrations—static filtration and cross-flow filtration (Fig. 20.3). In cross-flow filtration, the culture broth is pumped in across wise fashion across the membrane. This reduces the clogging process and hence better than the static filtration.

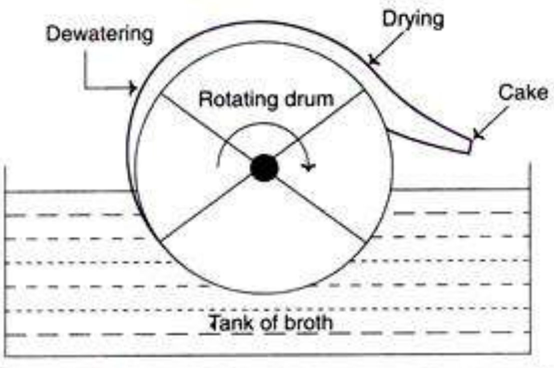


Fig. 20.2 : *Diagrammatic representation of a rotary drum vacuum filter.*

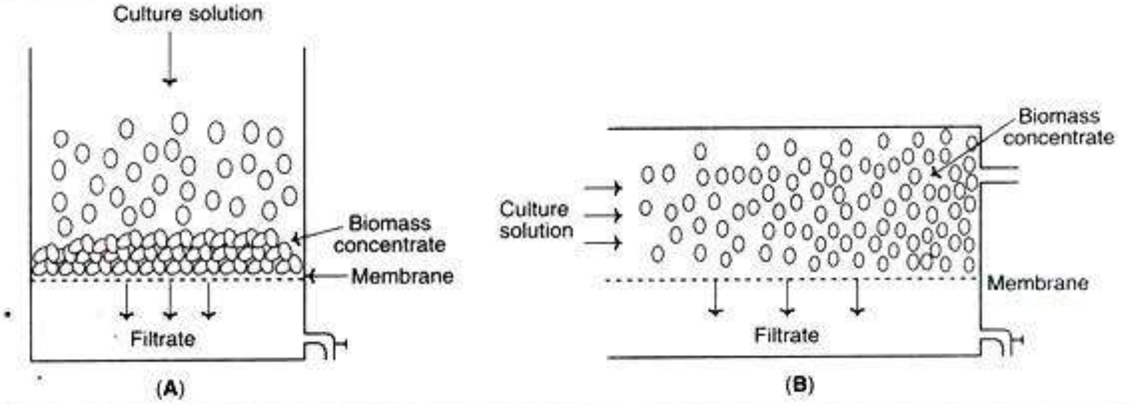


Fig. 20.3 : *Filter systems for separation of biomass and culture filtrate (A) Static–flow filtration (B) Cross–flow filtration.*

Types of filtration processes

There are 3 major types of filtrations based on the particle sizes and other characters (table20.1). These are:

1. Microfiltration
2. Ultra filtration
3. Reverse osmosis

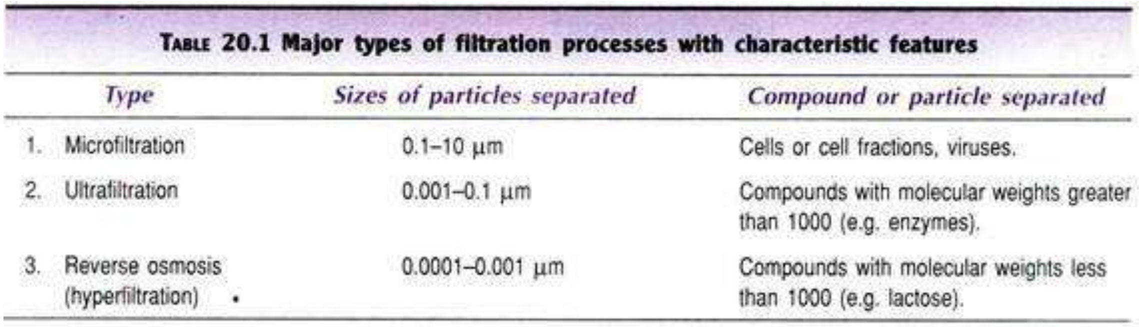


TABLE 20.1 Major types of filtration processes with characteristic features

	Type	*Sizes of particles separated*	*Compound or particle separated*
1.	Microfiltration	0.1–10 µm	Cells or cell fractions, viruses.
2.	Ultrafiltration	0.001–0.1 µm	Compounds with molecular weights greater than 1000 (e.g. enzymes).
3.	Reverse osmosis (hyperfiltration)	0.0001–0.001 µm	Compounds with molecular weights less than 1000 (e.g. lactose).

Centrifugation

The technique of centrifugation is based on the principle of density differences between the particles to be separated and the medium. Thus, centrifugation is mostly used for separating solid particles from liquid phase (fluid/particle separation). Unlike the centrifugation that is conveniently carried out in the laboratory scale, there are certain limitations for large scale industrial centrifugation. However, in recent years, continuous flow industrial centrifuges have been developed. There is a continuous feeding of the slurry and collection of clarified fluid, while the solids deposited can be removedintermittently.The different types of centrifges are depicted in Fig. 20.4, and briefly described hereunder.

i) Tubular bowl centrifuge (Fig. 20.4A):

This is a simple and a small centrifuge, commonly used in pilot plants. Tubular bowl centrifuge can be operated at a high centrifugal speed, and can be run in both batch and continuous mode. The solids are removed manually.

ii) Disc centrifuge (Fig. 20.4B):

It consists of several discs that separate the bowl into settling zones. The feed/slurry is fed through a central tube. The clarified fluid moves upwards while the solids settle at the lower surface.

iii) Multi-chamber centrifuge (Fig. 20.4C):

This is basically a modification of tubular bowl type of centrifuge. It consists of several chambers connected in such a way that the feed flows in a zigzag fashion. There is a variation in the centrifugal force in different chambers. The force is much higher in the periphery chambers, as a result smallest particles settle down in the outermost chamber.

iv) Scroll centrifuge or decanter (Fig. 20.4D):

It is composed of a rotating horizontal bowl tapered at one end. The decanter is generally used to concentrate fluids it high solid concentration (biomass content 5-80%). The solids are deposited on the wall of the bowl which can be scrapped and removed from the narrow end.

Stage 2. Release of Intracellular Products:

As already stated, there are several biotechnological products (vitamins, enzymes) which are located within the cells (intracellular). Such compounds have to be first released (maximally and in an active form) for their further processing and final isolation. The microorganisms or other cells can be disintegrated or disrupted by physical, chemical or enzymatic methods. The outline of different techniques used for breakage of cells is given in Fig. 20.5. The selection of a particular method depends on the nature of the cells, since there is a wide variation in the property of cell disruption or breakage.

Cell Disruption:

1. Physical methods of cell disruption:

i) Ultra sonication:

Ultrasonic disintegration is widely employed in the laboratory. However, due to high cost, it is not suitable for large-scale use in industries.

ii) Osmotic shock:

This method involves the suspension of cells (free from growth medium) in 20% buffered sucrose. The cells are then transferred to water at about 4°C. Osmotic shock is used for the release of hydrolytic enzymes and binding proteins from Gram-negative bacteria.

iii) Heat shock (thermolysis):

Breakage of cells by subjecting them to heat is relatively easy and cheap. But this technique can be used only for a very few heat-stable intracellular products.

iv) High pressure homogenization:

This technique involves forcing of cell suspension at high pressure through a very narrow orifice to come out to atmospheric pressure. This sudden release of high pressure creates a liquid shear that can break the cells.

v) Impingement:

In this procedure, a stream of suspended cells at high velocity and pressure are forced to hit either a stationary surface or a second stream of suspended cells (impinge literally means to strike or hit). The cells are disrupted by the forces created at the point of contact. Micro fluidizer is a device developed based on the principle of impingement. It has been successfully used for breaking E. coli cells. The advantage with impingement technique is that it can be effectively used for disrupting cells even at a low concentration.

vi) Grinding with glass beads:

The cells mixed with glass beads are subjected to a very high speed in a reaction vessel. The cells break as they are forced against the wall of the vessel by the beads. Several factors influence the cell breakage-size and quantity of the glass beads, concentration and age of cells, temperature and agitator speed. Under optimal conditions, one can expect a maximal breakage of about 80% of the cells. A diagrammatic representation of a cell disrupter employing glass beads is shown in Fig.20.6. It contains a cylindrical body with an inlet, outlet and a central motor-driven shaft. To this shaft are fitted radial agitators. The cylinder is fitted with glass beads. The cell suspension is added through the inlet and the disrupted cells come out through the outlet. The body of the cell disrupter is kept cool while the operation is on.

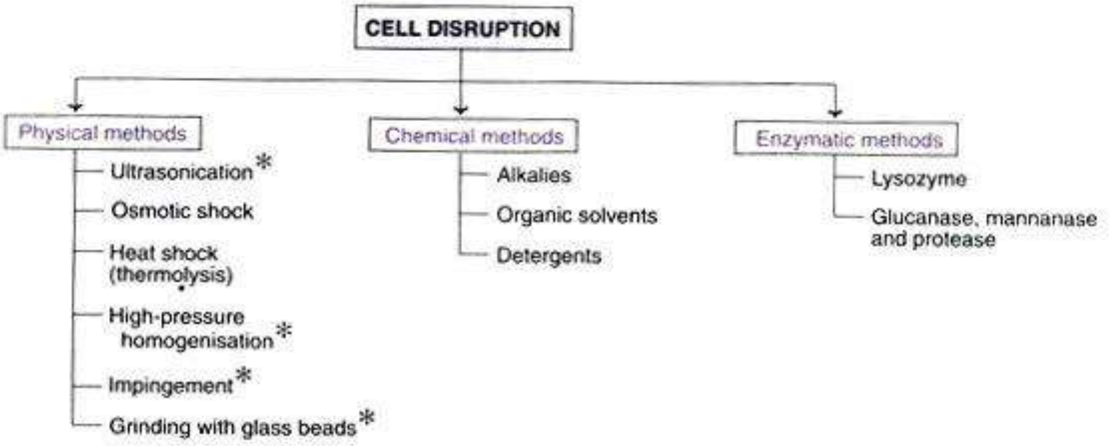


Fig. 20.5 : *Major methods for cell disruption to release the intracellular products (* indicate mechanical methods while all the remaining are non-mechanical).*

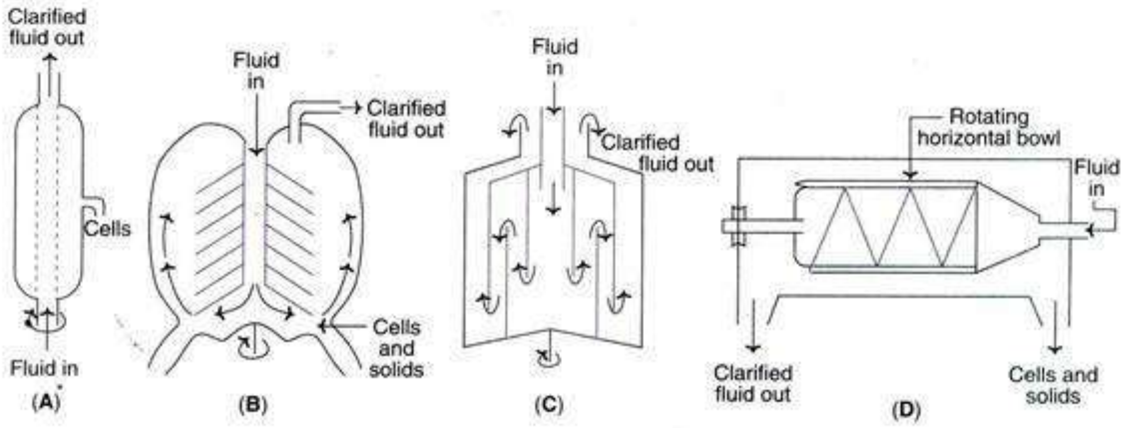


Fig. 20.4 : *Centrifuges commonly used in downstream processing (**A**) Tubular bowl centrifuge (**B**) Disc centrifuge (**C**) Multichamber centrifuge (**D**) Scroll centrifuge (decanter).*

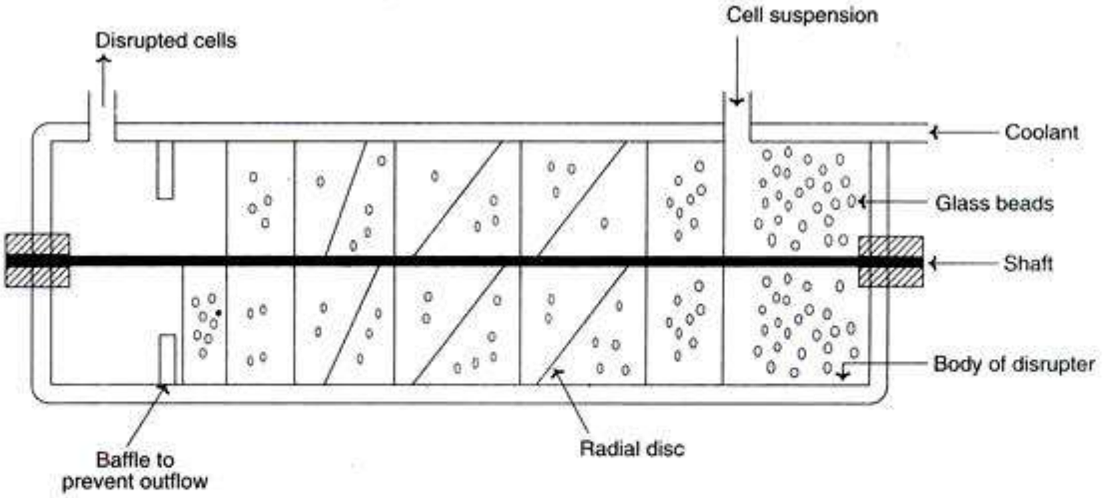


Fig. 20.6 : Diagrammatic representation of a cell disrupter.

Mechanical and non-mechanical methods

Among the physical methods of cell disruption described above, ultra sonication, highpressurehomogenization, impingement and grinding with glass beads are mechanical while osmotic shock and heat shock are non-mechanical. The chemical and enzymatic methods (described below) are non-mechanical in nature.

Chemical methods of cell disruption:

Treatment with alkalies, organic solvents and detergents can lyse the cells to release the contents.

i) Alkalies:

Alkali treatment has been used for the extraction of some bacterial proteins. However, the alkali stability of the desired product is very crucial for the success of this method e.g., recombinant growth hormone can be efficiently released from E. coli by treatment with sodium hydroxide at pH 11.

ii) Organic solvents:

Several water miscible organic solvents can be used to disrupt the cells e.g., methanol, ethanol, isopropanol, butanol. These compounds are inflammable; hence require specialisedequipment for fire safety. The organic solvent toluene is frequently used. It is believed that toluene dissolves membrane phospholipids and creates membrane pores for release of intracellular contents.

iii) Detergents:

Detergents that are ionic in nature, cationic-cetyl trimethyl ammonium bromide (CTAB) or anionic-sodium lauryl sulfate (SLS) can denature membrane proteins and lyse the cells. Nonionic detergents (although less reactive than ionic ones) are also used to some extent e.g., Triton X-100 or Tween. The problem with the use of detergents is that they affect purification steps, particularly the salt precipitation. This limitation can be overcome by using ultra filtration or ion-exchange chromatography for purification.

Enzymatic methods of cell disruption:

Cell disruption by enzymatic methods has certain advantages i.e., lysis of cells occurs under mild conditions in a selective manner. This is quite advantageous for product recovery.Lysozyme is the most frequently used enzyme and is commercially available (produced from hen egg white). It hydrolyses β-1, 4-glycosidic bonds of the mucopeptide in bacterial cell walls. The Gram- positive bacteria (with high content of cell wall mucopeptides) are more susceptible for the action of lysozyme. For Gram-negative bacteria, lysozyme in association with EDTA can break the cells. As the cell wall gets digested by lysozyme, the osmotic effects break the periplasmic membrane to release the intracellular contents. Certain other enzymes are also used, although less frequently, for cell disruption. For thelysis of yeast cell walls, glucanase and mannanase in combination with proteases are used.

Combination of methods:

In order to increase the efficiency of cell disintegration in a cost-effective manner, a combination of physical, chemical and enzymatic methods is employed.

Stage 3. Concentration:

The filtrate that is free from suspended particles (cells, cell debris etc.) usually contains 80-98% of water. The desired product is a very minor constituent. The water has to be removed to achieve the product concentration. The commonly used techniques for concentrating biological products are:

1. Evaporation
2. Liquid-liquid extraction
3. Membrane filtration
4. Precipitation
5. Adsorption.

The actual procedure adopted depends on the nature of the desired product (quality and quantity to be retained as far as possible) and the cost factor.

1. Evaporation:

Water in the broth filtrate can be removed by a simple evaporation process. The evaporators, in general, have a heating device for supply of steam, and unit for the separation of concentrated product and vapour, a condenser for condensing vapour, accessories and control equipment. Some of the important types of evaporators in common use are briefly described:

i) Plate evaporators:

The liquid to be concentrated flows over plates. As the steam is supplied, the liquid gets concentrated and becomes viscous.

ii) Falling film evaporators:

In this case, the liquid flows down long tubes which gets distributed as a thin film over the heating surface. Falling film evaporators are suitable for removing water from viscous products of fermentation.

iii) Forced film evaporators:

The liquid films are mechanically driven and these devices are suitable for producing dry product concentrates.

iv) Centrifugal forced film evaporators:

These equipment evaporate the liquid very quickly (in seconds), hence suitable for concentrating even heat-labile substances. In these evaporators, a centrifugal force is used to pass on the liquid over heated plates or conical surfaces for instantaneous vaporation

2. Liquid-Liquid Extraction:

The concentration of biological products can be achieved by transferring the desired product (solute) from one liquid phase to another liquid phase, a phenomenon referred to as liquidliquidextraction. Besides concentration, this technique is also useful for partial purification of a product. The efficiency of extraction is dependent on the partition coefficient i.e. the relative distribution of a substance between the two liquid phases. The process of liquid-liquid extraction may be broadly categorized as extraction of low molecular weight products and extraction of high molecular weight products.

Extraction of low molecular weight products:

By using organic solvents, the lipophilic compounds can be conveniently extracted. However, it is quite difficult to extract hydrophilic compounds. Extraction of lipophilicproducts can be done by the following techniques:

i) Physical extraction:

The compound gets itself distributed between two liquid phases based on the physical properties. This technique is used for extraction of non-ionising compounds.

ii) Dissociation extraction:

This technique is suitable for the extraction of ionisable compounds’. Certain antibiotics can be extracted by this procedure.

iii) Reactive extraction:

In this case, the desired product is made to react with a carrier molecule (e.g., phosphorus compound, aliphatic amine) and extracted into organic solvent. Reactive extraction procedure is quite useful for the extraction of certain compounds that are highly soluble in water (aqueous phase) e.g., organic acids.

iv. Supercritical fluid (SCF) extraction:

This technique differs from the above procedures, since the materials used for extraction are supercritical fluids (SCFs). SCFs are intermediates between gases and liquids and exist as fluids above their critical temperature and pressure. Supercritical CO2, with a low critical temperature and pressure is commonly used in the extraction. Supercritical fluid extraction is rather expensive, hence not widely used (SCF has been used for the extraction of caffeine from coffee beans, and pigments and flavor ingredients from biological materials).

Extraction of high molecular weight compounds:

Proteins are the most predominant high molecular weight products produced in fermentation industries. Organic solvents cannot be used for protein extraction, as they lose their biological activities. They are extracted by using an aqueous two-phase systems or reverse micelles formation.

i) Aqueous two-phase systems (ATPS):

They can be prepared by mixing a polymer (e.g., polyethylene glycol) and a salt solution (ammonium sulfate) or two different polymers. Water is the main component in ATPS, but the two phases are not miscible. Cells and other solids remain in one phase while the proteins are transferred to other phase. The distribution of the desired product is based on its surface and ionic character and the nature of phases. The separation takes much longer time by ATPS.

ii) Reverse miceller systems:

Reverse micelles are stable aggregates of surfactant molecules and water in organic solvents. The proteins can be extracted from the aqueous medium by forming reverse micelles. In fact, the enzymes can be extracted by this procedure without loss of biological activity.

3. Membrane Filtration:

Membrane filtration has become a common separation technique in industrial biotechnology. It can be conveniently used for the separation of biomolecules and particles, and for the concentration of fluids. The membrane filtration technique basically involves the use of a semipermeablemembrane that selectively retains the particles/molecules that are bigger than the pore size while the smaller molecules pass through the membrane pores. Membranes used in filtration are made up of polymeric materials such as polyethersulfoneand polyvinyl di-fluoride. It is rather difficult to sterilize membrane filters. In recent years, micro-filters and ultrafilters composed of ceramics and steel are available. Cleaning and sterilization of such filters are easy. The other types of membrane filtration techniques are described briefly

Membrane adsorbers:

They are micro- or macro porous membranes with ion exchange groups and/or affinity ligands.Membrane adsorbers can bind to proteins and retain them. Such proteins can be eluted by employing solutions in chromatography.

Pervaporation:

This is a technique in which volatile products can be separated by a process of permeation through a membrane coupled with evaporation. Pervaporation is quite useful for the extraction, recovery and concentration of volatile products. However, this procedure has a limitation since it cannot be used for large scale separation of volatile products due to cost factor.

Perstraction:

This is an advanced technique working on the principle of membrane filtration coupled with solvent extraction. The hydrophobic compounds can be recovered/ concentrated by this method.

Precipitation:

Precipitation is the most commonly used technique in industry for the concentration of macromolecules such as proteins and polysaccharides. Precipitation technique can also be employed for the removal of certain unwanted byproducts e.g. nucleic acids, pigments. Neutral salts, organic solvents, high molecular weight polymers (ionic or non-ionic), besides alteration in temperature and pH are used in precipitation. In addition to these non-specific protein precipitation reactions (i.e. the nature of the protein is unimportant), there are some protein specific precipitations e.g., affinity precipitation, ligand precipitation.

i) Neutral salts:

The most commonly used salt is ammonium sulfate, since it is highly soluble, nontoxic to proteins and low-priced. Ammonium sulfate increases hydrophobic interactions between protein molecules that result in their precipitation. The precipitation of proteins is dependent on several factors such as protein concentration, pH and temperature.

ii) Organic solvents:

Ethanol, acetone and propanol are the commonly used organic solvents for protein precipitation. They reduce the dielectric constant of the medium and enhance electrostatic interaction between protein molecules that lead to precipitation. Since proteins are denatured by organic solvents, the precipitation process has to be carried out below 0°C.

iii) Non-ionic polymers:

Polyethylene glycol (PEG) is a high molecular weight non-ionic polymer that cans precipitate proteins. It reduces the quantity of water available for protein solvation and precipitates protein. PEG does not denature proteins, besides being non-toxic.

iv) Ionic polymers:

The charged polymers such as polyacrylic acid and lyethyleneimine are used. They form complexes with oppositely charged protein molecules that causes charge neutralization and precipitation.

v) Increase in temperature:

The heat sensitive proteins can be precipitated by increasing the temperature.

vi) Change in pH:

Alterations in pH can also lead to protein precipitation.

vii) Affinity precipitation:

The affinity interaction (e.g., between antigen and antibody) is exploited for precipitation of proteins.

Viii) Precipitation by ligands:

Ligands with specific binding sites for proteins have been successfully used for selective precipitation.

5. Adsorption:

The biological products of fermentation can be concentrated by using solid adsorbent particles. In the early days, activated charcoal was used as the adsorbent material. In recent years, cellulose-based adsorbents are employed for protein concentration. And for concentration of low molecular weight compounds (vitamins, antibiotics, peptides) polystyrene, methacrylate and acrylate based matrices are used. The process of adsorption can be carried out by making a bed of adsorbent column and passing the culture broth through it. The desired product, held by the adsorbent, can be eluted.

Stage 4: Purification by Chromatography:

The biological products of fermentation (proteins, pharmaceuticals, diagnostic compounds and research materials) are very effectively purified by chromatography. Chromatography is basically an analytical technique dealing with the separation of closely related compounds from a mixture. Chromatography usually consists of a stationary phase and mobile phase. The stationary phase is the porous solid matrix packed in a column (equilibrated with a suitable solvent) on to which the mixture of compounds to be separated is loaded. The compounds are eluted by a mobile phase.

A single mobile phase may be used continuously or it may be changed appropriately to facilitate the release of desired compounds. The eluate from the column can be monitored continuously (e.g. protein elution can be monitored by ultraviolet adsorption at 280 nm), and collected in fractions of definite volumes.

The different types of chromatography techniques used for separation (mainly proteins) along with the principles are given in Table 20.2. A large number of matrices are commercially available for purification of proteins e.g., agarose, cellulose, polyacrylamide, porous silica, cross- linked dextran, polystyrene. Some of the important features of selected chromatographic techniques are briefly described.

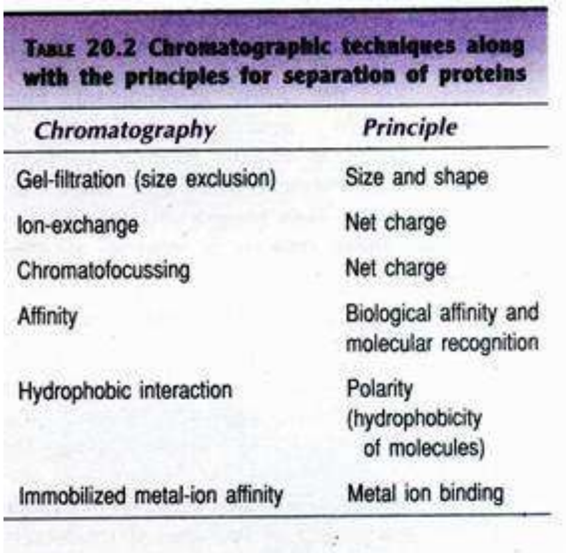


Table 20.2 Chromatographic techniques along with the principles for separation of proteins

Chromatography	*Principle*
Gel-filtration (size exclusion)	Size and shape
Ion-exchange	Net charge
Chromatofocussing	Net charge
Affinity	Biological affinity and molecular recognition
Hydrophobic interaction	Polarity (hydrophobicity of molecules)
Immobilized metal-ion affinity	Metal ion binding

i) Gel-filtration chromatography:

This is also referred to as size-exclusion chromatography. In this technique, the separation of molecules is based on the size, shape and molecular weight. The sponge-like gel beads with pores serve as molecular sieves for separation of smaller and bigger molecules. A solution mixture containing molecules of different sizes (e.g. different proteins) is applied to the column and eluted.

The smaller molecules enter the gel beads through their pores and get trapped. On the other hand, the larger molecules cannot pass through the pores and therefore come out first with the mobile liquid (Fig. 20.7). At the industrial scale, gel-filtration is particularly useful to remove salts and low molecular weight compounds from high molecular weight products.

Fig. 20.7 : The principle of gel-filtration chromatography.

ii) Ion-exchange chromatography:

It involves the separation of molecules based on their surface charges. Ion-exchangers are of two types (cation- exchangers which have negatively charged groups like carboxymethyl andsulfonate, and anion- exchangers with positively charged groups like diethylaminoethyl (DEAE).The most commonly used cation-exchangers are Dowex HCR and Amberlite IR, the anionexchangersare Dowex SAR and Amberlite IRA.

In ion-exchange chromatography, the pH of the medium is very crucial, since the net charge varies with pH. In other words, the pH determines the effective charge on both the target molecule and the ion-exchanger. The ionic bound molecules can be eluted from the matrix by changing the pH of the eluant or by increasing the concentration of salt solution. Ion-exchange chromatography is useful for the purification of antibiotics, besides the purification of proteins.

iii) Affinity chromatography:

This is an elegant method for the purification of proteins from a complex mixture. Affinity chromatography is based on an interaction of a protein with an immobilized ligand. The ligandcan be a specific antibody, substrate, substrate analogue or an inhibitor. The immobilizedligand on a solid matrix can be effectively used to fish out complementary structures. In Table 20.3, some examples of ligands used for the purification of proteins are given. The protein bound to the ligand can be eluted by reducing their interaction. This can be achieved by changing the pH of the buffer, altering the ionic strength or by using another free ligand molecule. The fresh ligand used has to be removed in the subsequent steps.

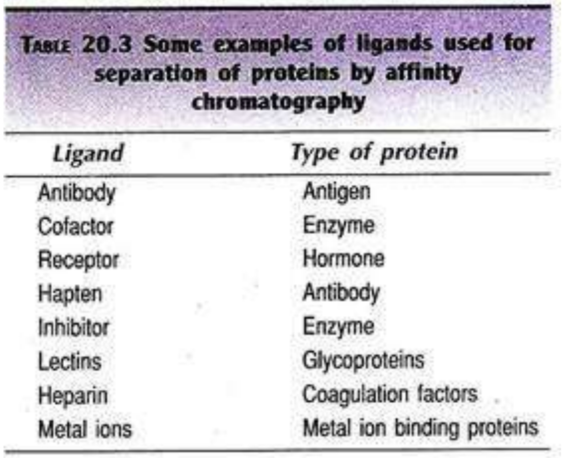


TABLE 20.3 Some examples of ligands used for separation of proteins by affinity chromatography

Ligand	*Type of protein*
Antibody	Antigen
Cofactor	Enzyme
Receptor	Hormone
Hapten	Antibody
Inhibitor	Enzyme
Lectins	Glycoproteins
Heparin	Coagulation factors
Metal ions	Metal ion binding proteins

Stage 5. Formulation:

Formulation broadly refers to the maintenance of activity and stability of a biotechnological product during storage and distribution. The formulation of low molecular weight products (solvents, organic acids) can be achieved by concentrating them with removal of most of the water. For certain small molecules,(antibiotics, citric acid), formulation can be done by crystallization by adding salts. Proteins are highly susceptible for loss of biological activity; hence their formulation requires special care. Certain stabilizing additives are added to prolong the shelf life of protein. The stabilizers of protein formulation include sugars (sucrose, lactose), salts (sodium chloride, ammonium sulfate), polymers (polyethylene glycol) and polyhydric alcohols (glycerol).Proteins may be formulated in the form of solutions, suspensions or dry powders.

1. Drying:

Drying is an essential component of product formulation. It basically involves the transfer of heat to a wet product for removal of moisture. Most of the biological products of fermentation are sensitive to heat, and therefore require gentle drying methods. Based on the method of heat transfer, drying devices may be categorized as contact, convection, radiation dryers. These three types of dryers are commercially available.

2. Spray drying:

Spray drying is used for drying large volumes of liquids. In spray drying, small droplets of liquid containing the product are passed through a nozzle directing it over a stream of hot gas. The water evaporates and the solid particles are left behind.

3. Freeze-drying/ Lyophilization

Freeze-drying or lyophilization is the most preferred method for dryingandformulation of a wide-range of products, pharmaceuticals, foodstuffs, diagnostics, bacteria, viruses. This is mainly because freeze-drying usually does not cause loss of biological activity of the desired product.

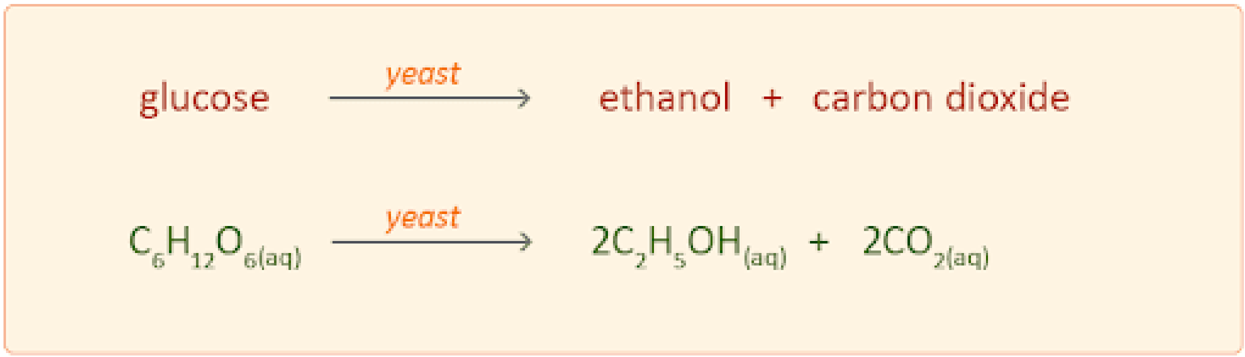
Lyophilization is based on the principle of sublimation of a liquid from a frozen state. In the actual technique, the liquid containing the product is frozen and then dried in a freeze-dryer under vacuum. The vacuum can now be released and the product containing vials can be sealed e.g., penicillin can be freeze dried directly in ampules.

UNIT IV

ALCOHOL PRODUCTION

Ethanol Production

Ethanol is a type of alcohol produced by fermentation of sugars and starches or cellulosic biomass. Ethanol is a clean-burning, high-octane fuel that is produced from renewable sources. Ethanol is a colourless, flammable, oxygenated hydrocarbon liquid. Chemical Formula is C_2H_5OH and has a boiling point of 78.50^oC in the anhydrous state.



$$\text{glucose} \xrightarrow{\text{yeast}} \text{ethanol} + \text{carbon dioxide}$$

$$C_6H_{12}O_{6(aq)} \xrightarrow{\text{yeast}} 2C_2H_5OH_{(aq)} + 2CO_{2(aq)}$$

Physical properties of Ethanol

Colorless liquid.

Pleasant alcoholic odor detectable at 49 to 716 ppm.

Miscible with water and most organic solvents.

Melting Point (°C): -114.1

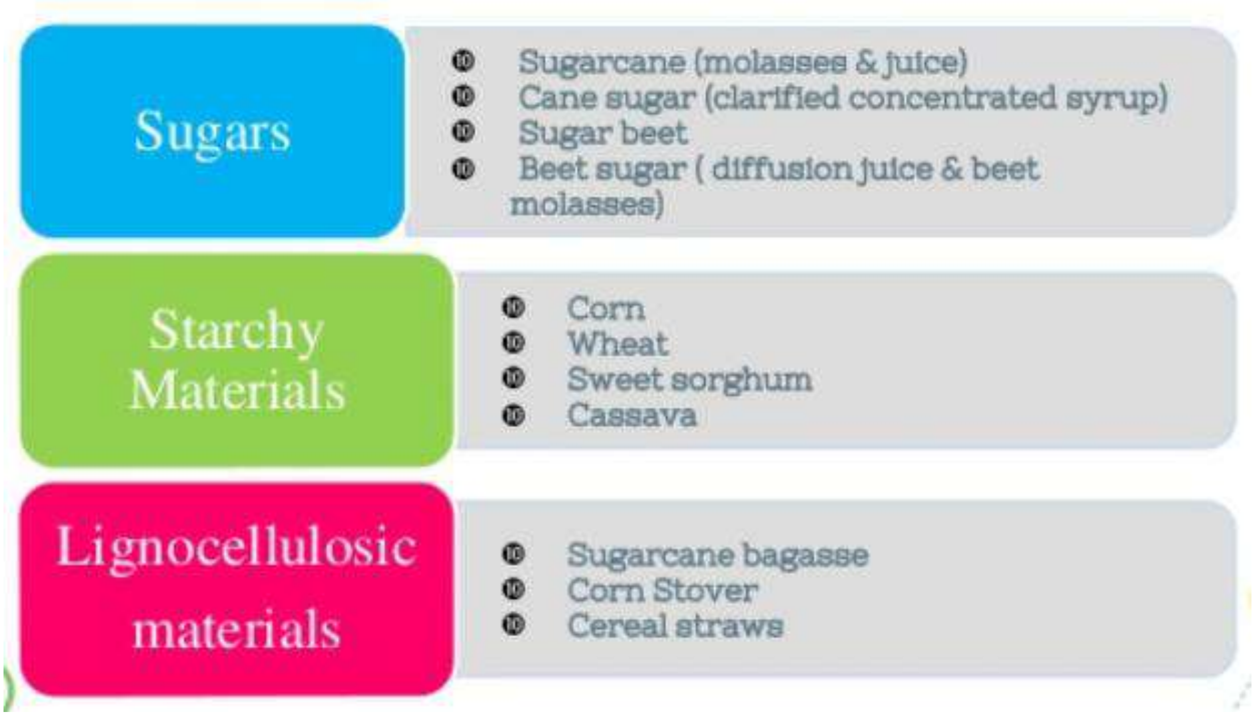
Octane 98-100

Boiling Point (°C): 78.3

Specific Gravity: 0.789

Vapor Density: 1.6

Raw materials



Sugars

- Sugarcane (molasses & juice)
- Cane sugar (clarified concentrated syrup)
- Sugar beet
- Beet sugar (diffusion juice & beet molasses)

Starchy Materials

- Corn
- Wheat
- Sweet sorghum
- Cassava

Lignocellulosic materials

- Sugarcane bagasse
- Corn Stover
- Cereal straws

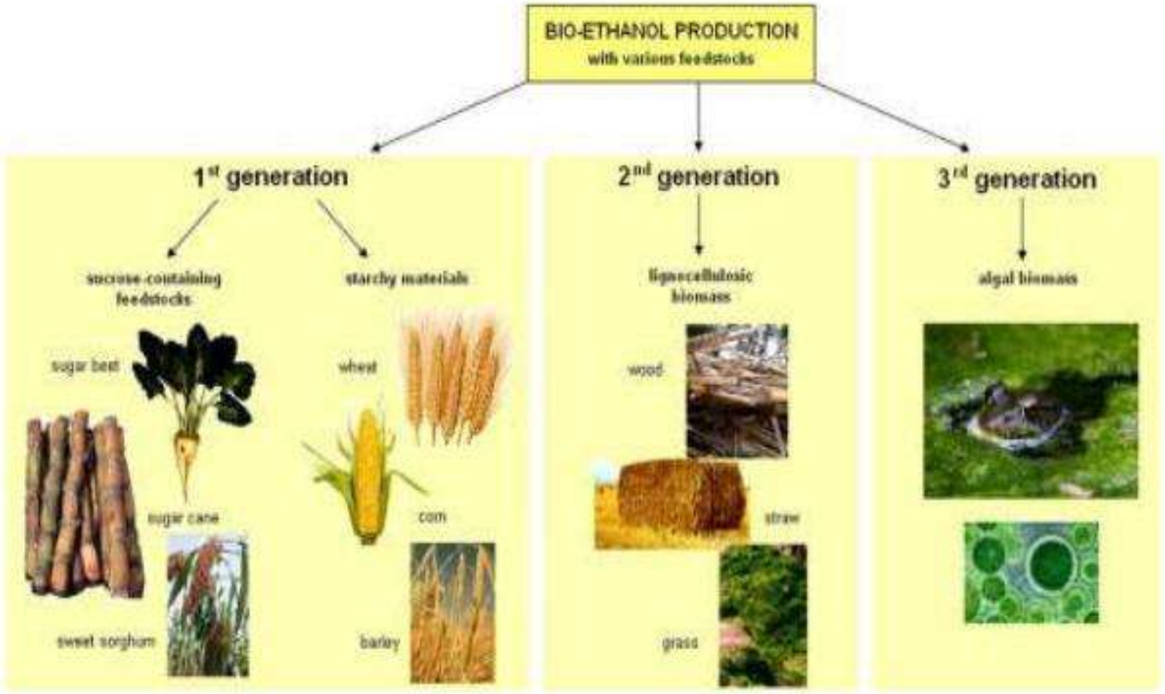
Raw materials (Sugar)

Materials containing sugar require the least costly preparation, as the sugars are already available in the degradable form.

Sucrose occurs in free form in sugarcane, and clarified can juice may be used directly for ethanol production. However, molasses is used rather than the corresponding juices for various reasons.

This class of raw materials is relatively the most expensive to obtain since it has other markets. Sugar beets and sweet sorghum also have potential for ethanol production, but sweet sorghum juice contains some starch and aconitic acid that cause difficulties in sugar crystallization.

SUBSTRATES AND MEDIA FOR ETHANOL PRODUCTION



Raw materials (Starchy)

Starch or carbohydrate is an attractive feedstock for many fermentation processes. High yields and starch content (50—60 percent) give corn an advantage. Spoiled and low-quality starches, not suitable for food or animal feed, can be effectively used for the production of alcohol. Even if food-grade starch is used, the resulting biomass byproduct represents an excellent, protein-fortified human or animal food.

Potatoes and cassava offers a high yield of starch per hectare of cropland, but the problem of storage to allow year-round ethanol production has not been overcome. Cassava, one of the most efficient photosynthetic plants, contains 20-35 percent starch and 1-2 percent protein.

Lignocellulose

Lignocellulose refers to the materials constituting the essential part of the cell wall of plants, i.e. cellulose, hemicellulose, and lignin

Lignocellulose refers to plant dry matter, so called lignocellulosic biomass. It is the most abundantly available raw material on the Earth for the production of biofuels, mainly bio-ethanol. It is composed of carbohydrate polymers, and an aromatic polymer.

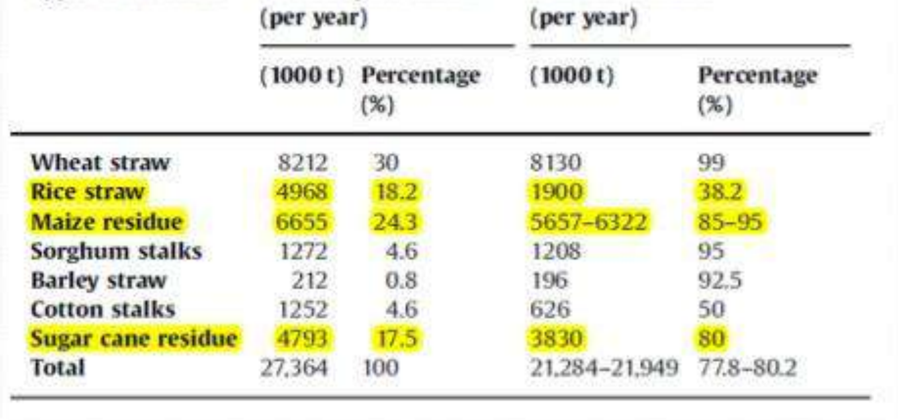
Raw materials (Lignocellulosic)

Lignocellulose is the major renewable from the carbohydrate in the world. It has been estimated that about 100 Gt cellulose is produced worldwide each year, a significant fraction of this occurs as municipal and agricultural waste. The energy crisis of the 1970s created renewed interest in the use of cellulose, but it is still difficult to convert it efficiently to its degradable manomer sugar units. A substantial improvement in cellulose hydrolysis technology is required before this resource material can be used on a large scale as a biomass feed stock for ethanol production.

While there are great quantities of urban and industrial wastes which require processing for environmental reason, these materials are so widely distributed that only a few isolated sources have economic potential. The collection, transportation, concentration and storage of these materials present technological difficulties.

Lignocellulosic Biomass

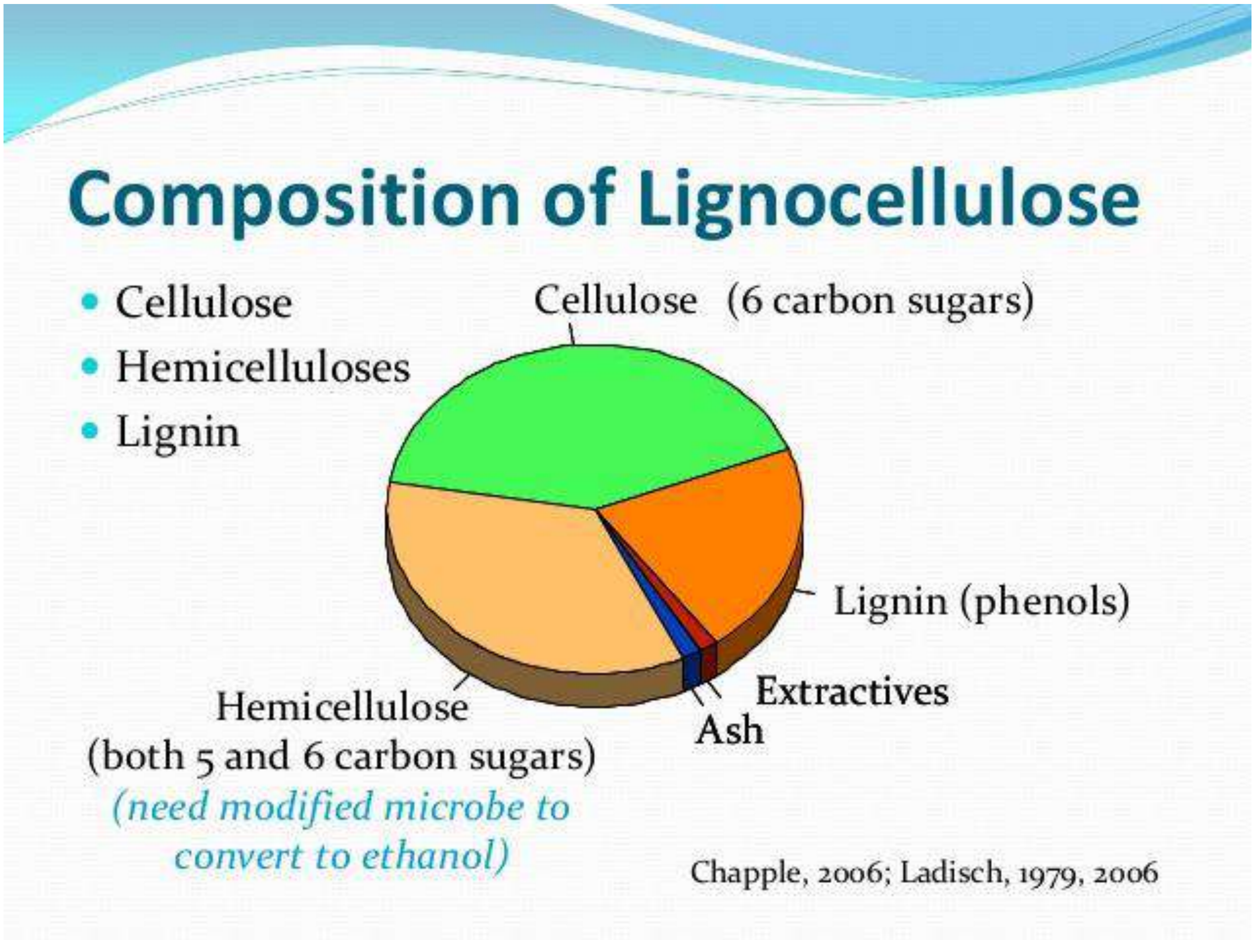
- Agricultural Residues:



Estimated crop residue generation and utilization in Egypt during the year 2004

Types of residues	Residue generation (per year)		Total utilization (per year)	
	(1000 t)	Percentage (%)	(1000 t)	Percentage (%)
Wheat straw	8212	30	8130	99
Rice straw	4968	18.2	1900	38.2
Maize residue	6655	24.3	5657–6322	85–95
Sorghum stalks	1272	4.6	1208	95
Barley straw	212	0.8	196	92.5
Cotton stalks	1252	4.6	626	50
Sugar cane residue	4793	17.5	3830	80
Total	27,364	100	21,284–21,949	77.8–80.2

Source: Quantitative appraisal of biomass resource and their energy potential in Egypt; 2013



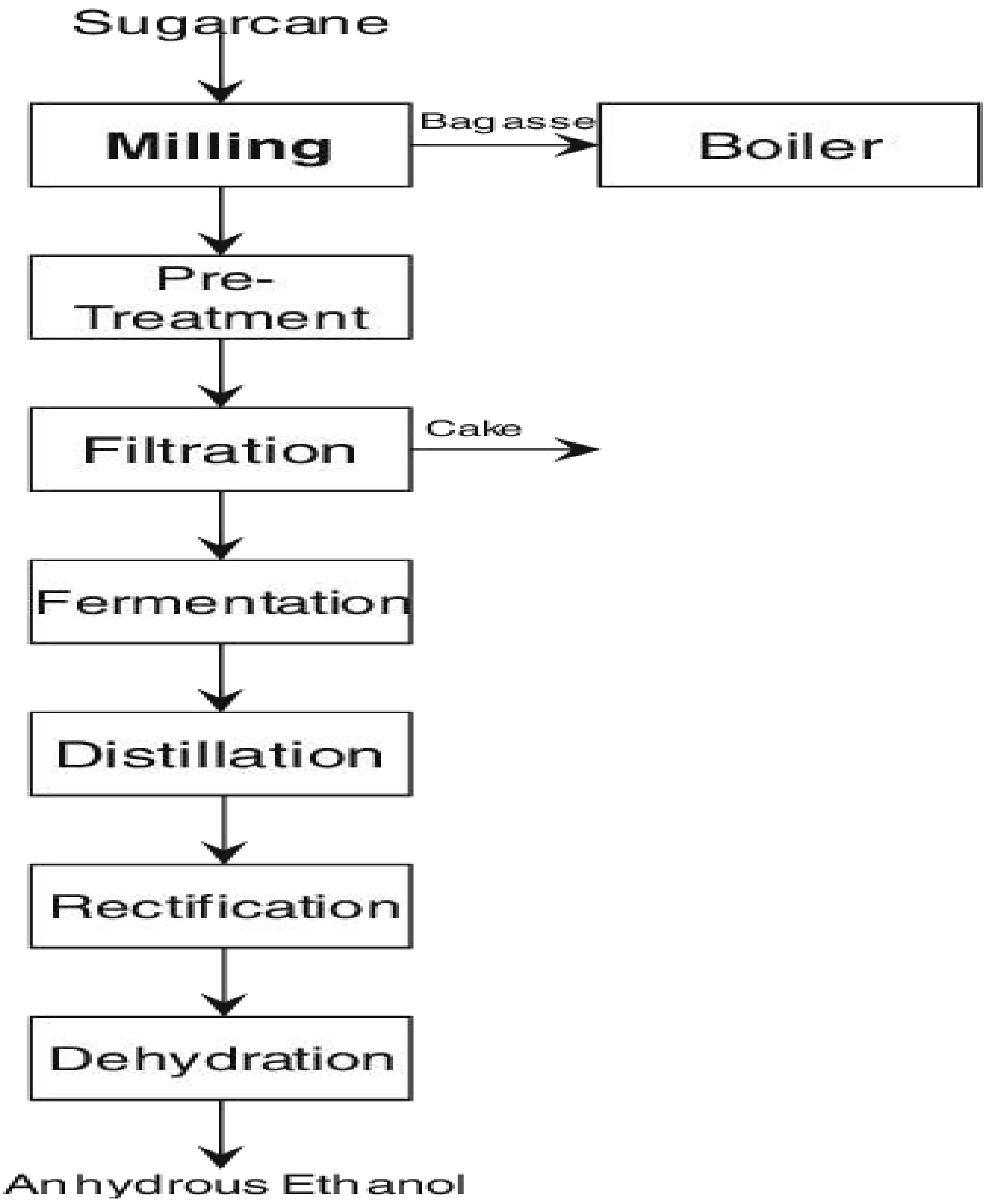
Composition of Lignocellulose

- Cellulose
- Hemicelluloses
- Lignin

(need modified microbe to convert to ethanol)

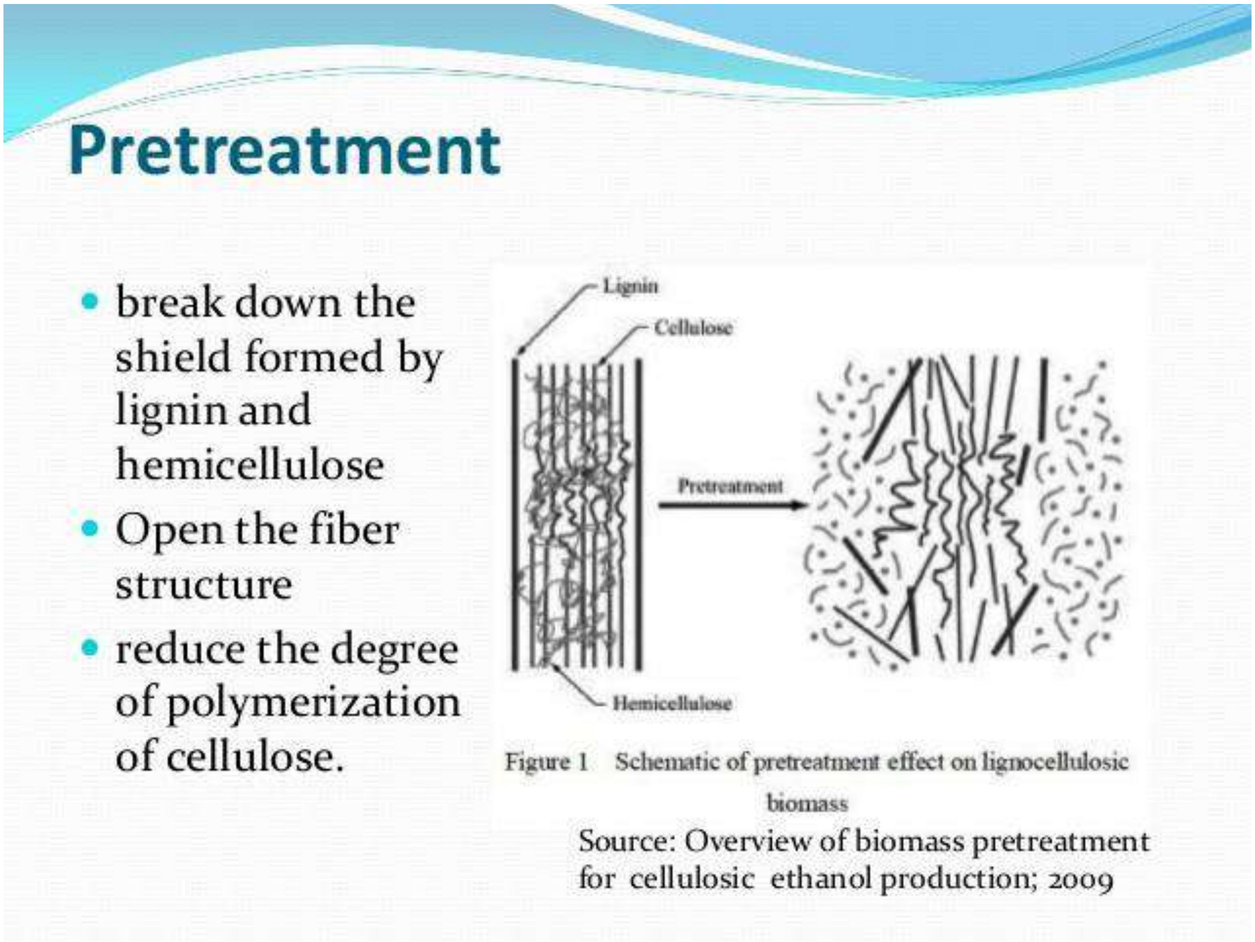
Chapple, 2006; Ladisch, 1979, 2006

Ethanol production from sugarcane



Milling

Mechanical crushing of the cereal grain to release the starch component. The feedstock passes through a hammer mill which grinds it into a fine powder called meal.



Pretreatment

- break down the shield formed by lignin and hemicellulose
- Open the fiber structure
- reduce the degree of polymerization of cellulose.

Figure 1 Schematic of pretreatment effect on lignocellulosic biomass

Source: Overview of biomass pretreatment for cellulosic ethanol production; 2009

Pretreatment

The fibre component of cellulosic biomass, hemi cellulose and cellulose, can be hydrolyse, but the structural features of cellulose, such as the degree of crystalline, the degree of polymerization, the degree of water swelling and surface area, make it less amenable to hydrolysis. Some form of pretreatment is, therefore, necessary to obtain high yields of monosaccharides.

Several techniques have been proposed to enhance the degree of hydrolysis of lignocellulosic to sugars. These techniques are generally classified as physical, chemical, biological or a combination of these, according to their mode of action. These techniques are generally classified as physical, chemical, biological or a combination of these, according to their mode of action. The physical pretreatment involves particle reduction to very small mesh sizes. The shearing and compressive forces involved in milling cause a reduction in crystallinity, a decrease in the mean degree of polymerization and an increase in bulk density. The milled material also allows for a high slurry concentration, thereby reducing the reactor volume and hence, capital cost. In general, the power requirements for these grinding or milling methods are so large as to make them quite expensive chemical treatments with strong acids or bases, such as sulphuric acid or sodium hydroxide, or with other cellulose swelling or dissolving agents also effectively increase hydrolysis. These chemicals are generally quite corrosive and expensive and must be recovered for reuse. Furthermore, they are often toxic or inhibitory to micro organisms (or their enzymes) so that their removal from the pretreated cellulosic materials must be almost complete. All these factors combine to increase the expense and difficulty of such chemical treatment methods.

Another technique of current interest is the steam explosion process (Muzzy et al. 1982). Lignocellulosic materials (usually wood chips) are saturated with water under pressure of 2000—3400 KPa (21—35 kg/cm2) at elevated temperatures (215–260°C). When the pressure is released, the water evaporates rapidly and the wood fibres tend to separate. In addition, the moisture and high temperature liberate acetic acid which catalyses the hydrolysis of the hemicellulose.Although this process is very effective, it requires considerable thermal energy and some of the sugars are inevitably degraded by the high temperatures involved.

Fermentation

Fermentation of the mash using yeast. Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash is allowed to flow through several fermenters until it is fully fermented and leaves the final tank. In a batch process, the mash stays in one fermenter for about 48 hours before the distillation process is started. Unicellular fungus (more than 1000 species identified. Commonly used to leaven bread and ferment alcoholic beverages Most yeasts belong to the division Ascomycota A few yeasts (eg., Candida albicans) can cause infection in humans Saccharomyces cerevisiae (most commonly used yeast), was domesticated for wine, bread, and beer production 2000+ yrs ago Yeast physiology can be either obligately aerobic or facultatively anaerobic (fermentative)There is no known obligately anaerobic yeast In absence of O2, fermentative yeasts produce energy by converting sugars into carbon dioxide and ethanol (alcohol)In brewing, ethanol is the desired product, while in baking, carbon dioxide raises the bread and the ethanol evaporates Many yeasts can be isolated from sugar-rich environmental samples such as fruits and berries (grapes, apples, peachesetc.) and exudates from plants (such as plant saps or cacti).The most common mode of vegetative growth in yeast is the asexual reproduction by budding or fission. A small bud (daughter cell), is formed on the parent cell The nucleus of the parent cell splits into a daughter nucleus and migrates into the daughter cell The bud continues to grow until it separates from the parent cell, forming a new cell. In brewing beer, top-fermenting yeasts (float to the top of the beer) produce higher alcohol concentrations and prefer higher temperatures (15-25 °C)– Eg., Saccharomyces cerevisiae (known to brewers as ale yeast)They produce fruitier, sweeter type ale beers Bottom-fermenting yeasts ferment more sugars, leaving a crisper taste and work well at low temperatures (5-10 °C) Eg., Saccharomycesuvarum(formerlyknownas

Saccharomyces)carlsbergensi They are used in producing lager-type beers Brewers of wheat beers often use varieties of Torulasporadelbrueckii.

Principle of fermentation

Summarizing chemical equation for ethanol fermentation:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

One glucose molecule is converted into two ethanol molecules and two carbon dioxide molecules. The most common micro organism, the yeast Saccharomyces cerevisiae. Higher concentrations upto 95% are produced by distilling and fractionating. When distilled, the remaining constant boiling point mixture is 95% ethanol, 5% water. Anhydrous ethanol is produced commercially with azeotropic removal of water by co-distillation with solvents such as benzene. Only about 0.5% of the energy potential of the sugars is lost during fermentation, but significant amounts of process heat are required for the concentration and separation processes. This process heat may be provided by the combustion or gasification of otherwise waste biomass.

Application

Fuel Application

Transport fuel to replace gasoline

Fuel for power generation by thermal combustion

Fuel for fuel cells by thermo chemical reaction

Fuel in cogeneration systems

Feedstock in the chemicals industry

Blending of ethanol with a small proportion of a volatile fuel such as gasoline -> more cost effective

Various mixture of bioethanol with gasoline or diesel fuels

E5G to E26G (5-26% ethanol, 95-74% gasoline)

E85G (85% ethanol, 15% gasoline)

E15D (15% ethanol, 85% diesel)

E95D (95% ethanol, 5% water, with ignition improver

Exhaust gases of ethanol are much cleaner. it burns more cleanly as a result of more complete combustion, Greenhouse gases reduce ethanol-blended fuels such as E85 (85% ethanol and 15% gasoline) reduce up to 37.1% of GHGs.Positive energy balance, depending on the type of raw stock output of energy during the production is more than the input. Any plant can be use for production of bioethanol .It only has to contain sugar and starch.

Carbon neutral

The CO2 released in the bioethanol production process is the same amount as the one the crops previously absorbed during photosynthesis.

Decrease in ozone formation

The emissions produced by burning ethanol are less reactive with sunlight than those produced by burning gasoline, which results in a lower potential for forming ozone.

Renewable energy resource

Result of conversion of the sun's energy into usable energy

Photosynthesis -> feed stocks grow -> processed into ethanol

Energy security

Countries that do not have access to crude oil resources grow crops for energy use and gain some economic freedom.

Reduces the **amount of high-octane additives**

Fuel spills are more easily biodegraded or diluted to non toxic concentrations.

Disadvantages and Concerns

Biodiversity

A large amount of arable land is required to grow crops, natural habitats would be destroyed.

Food vs. Fuel debate

Due to the lucrative prices of bioethanol some farmers may sacrifice food crops for biofuel production which will increase food prices around the world.

Carbon emissions (controversial)

During production of bioethanol, huge amount of carbon dioxide is released. Emission of GHGs from production of bioethanol is comparable to the emissions of internal-combustion engines.

Not as efficient as petroleum

Energy content of the petrol is much higher than bioethanol .its energy content is 70% of that of petrol

Engines made for working on Bioethanol cannot be used for petrol or diesel

Due to high octane number of bioethanol, they can be burned in the engines with much higher compression.

Transportation

Ethanol is hygroscopic; it absorbs water from the air and thus has high corrosion aggressiveness. Can only be transported by auto transport or railroad. Many older cars unequipped to handle even 10% ethanol.

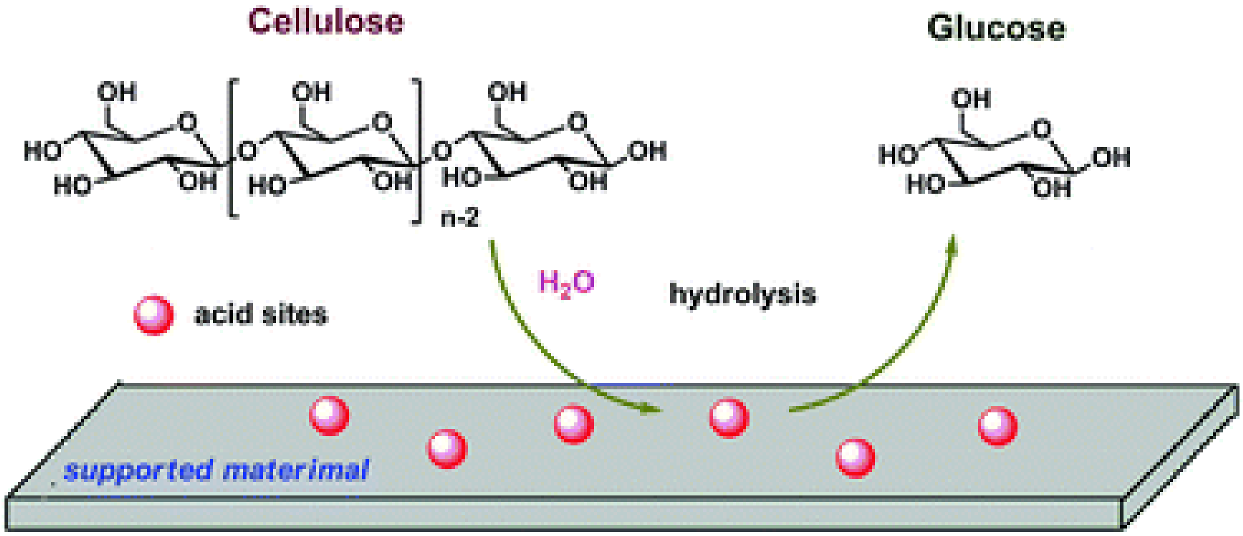
Hydrolysis

Hydrolysis process breaks own the biomass (cellulosic) portion into sugar solution which will be then be fermented into ethanol.

Types of Hydrolysis

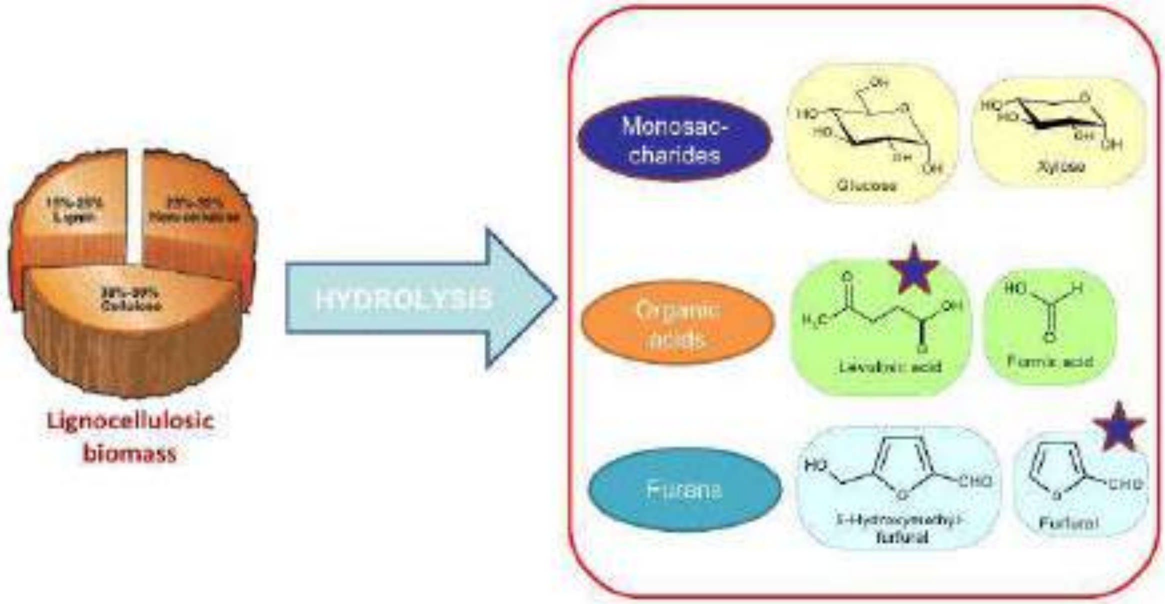
Acid hydrolysis, concentrated acid hydrolysis, Dilute acid hydrolysis, Enzyme hydrolysis

As the main component of lignocelluloses, cellulose is a biopolymer consisting of many glucose units connected through β-1, 4-glycosidic bonds. Breakage of the β-1,4-glycosidic bonds by acids leads to the hydrolysis of cellulose polymers, resulting in the sugar molecule glucose or oligosaccharides. Mineral acids, such as HCl and H_2SO_4, have been used in the hydrolysis of cellulose.

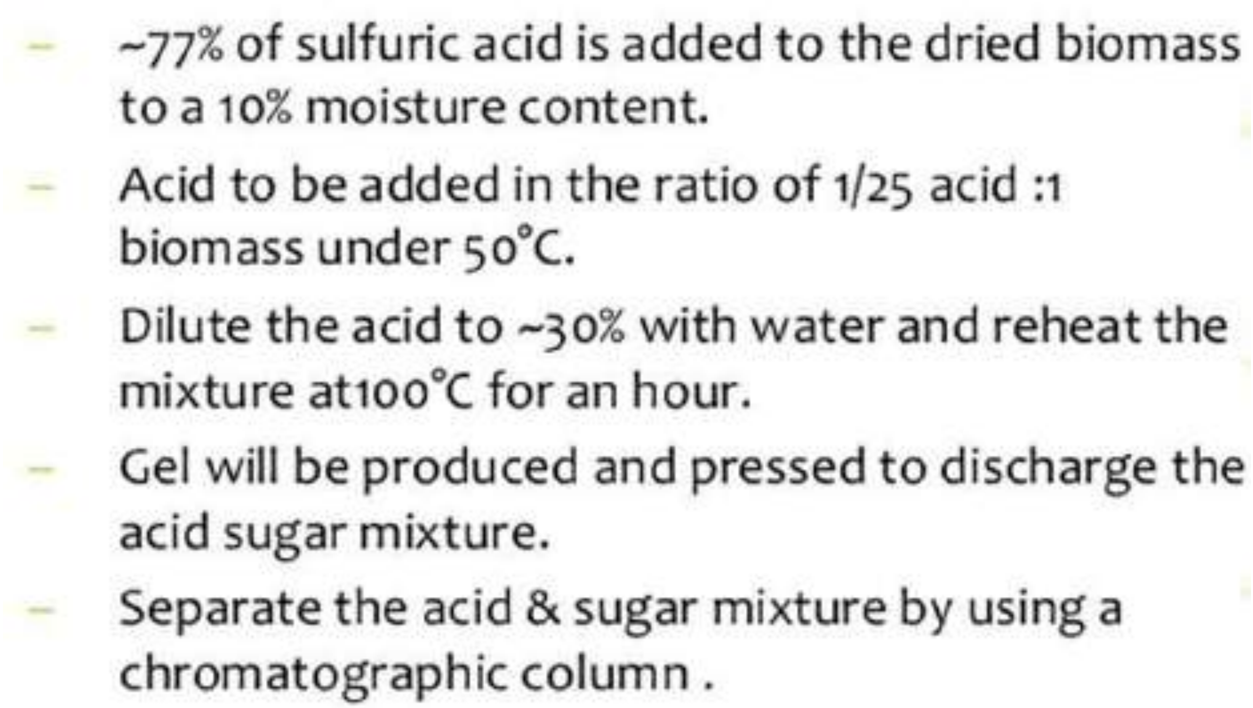


i.e. metal-oxides, ion-exchange resins, sulfonated carbonaceous based acids, H-form zeolites, magnetic solid acids, supported metal catalysts,heteropoly acids

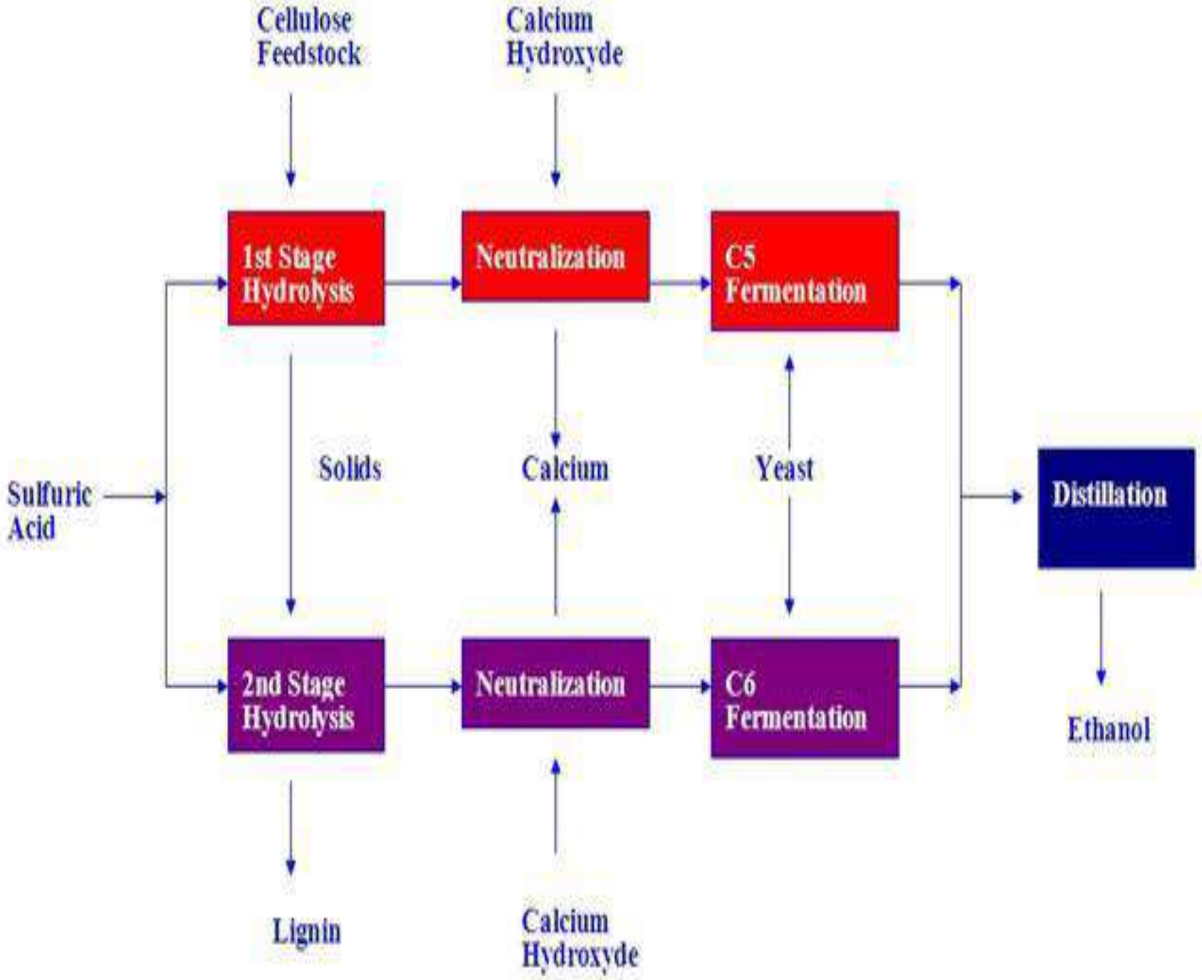
Hydrolysis of biomass

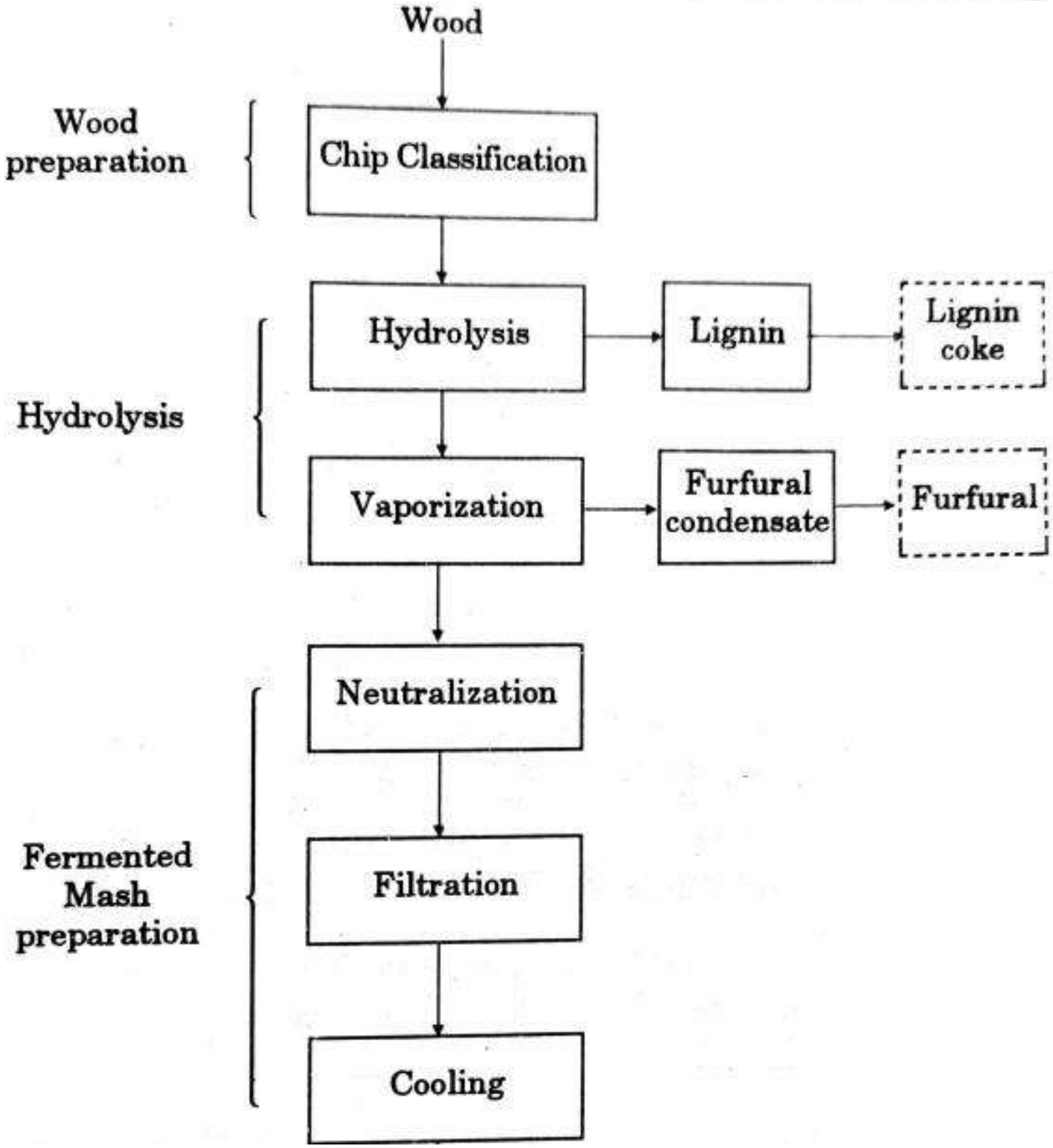


Concentrated Acid Hydrolysis



- ~77% of sulfuric acid is added to the dried biomass to a 10% moisture content.
- Acid to be added in the ratio of 1/25 acid :1 biomass under 50°C.
- Dilute the acid to ~30% with water and reheat the mixture at100°C for an hour.
- Gel will be produced and pressed to discharge the acid sugar mixture.
- Separate the acid & sugar mixture by using a chromatographic column .


Cellulose Feedstock
Calcium Hydroxyde
1st Stage Hydrolysis
Neutralization
C5 Fermentation
Sulfuric Acid
Solids
Calcium
Yeast
Distillation
2nd Stage Hydrolysis
Neutralization
C6 Fermentation
Ethanol
Lignin
Calcium Hydroxyde


Wood
Wood preparation
Chip Classification
Hydrolysis
Hydrolysis
Lignin
Lignin coke
Vaporization
Furfural condensate
Furfural
Fermented Mash preparation
Neutralization
Filtration
Cooling

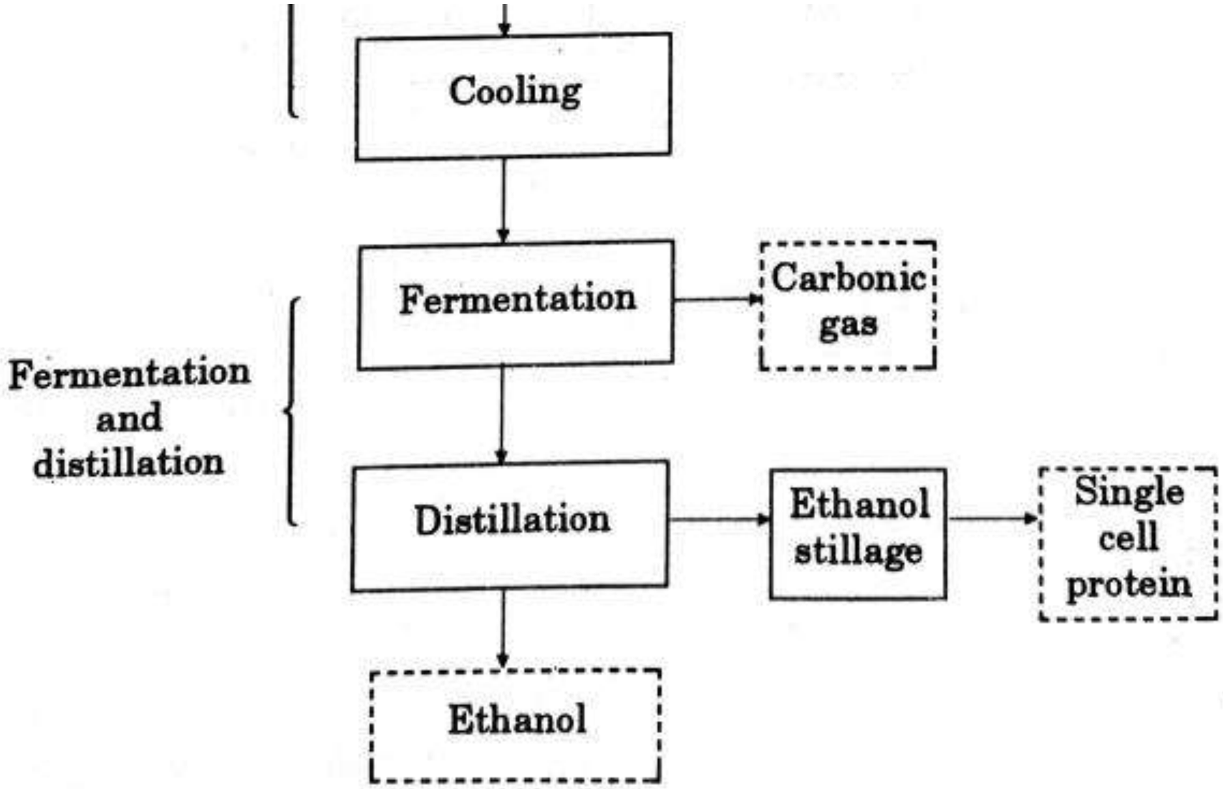
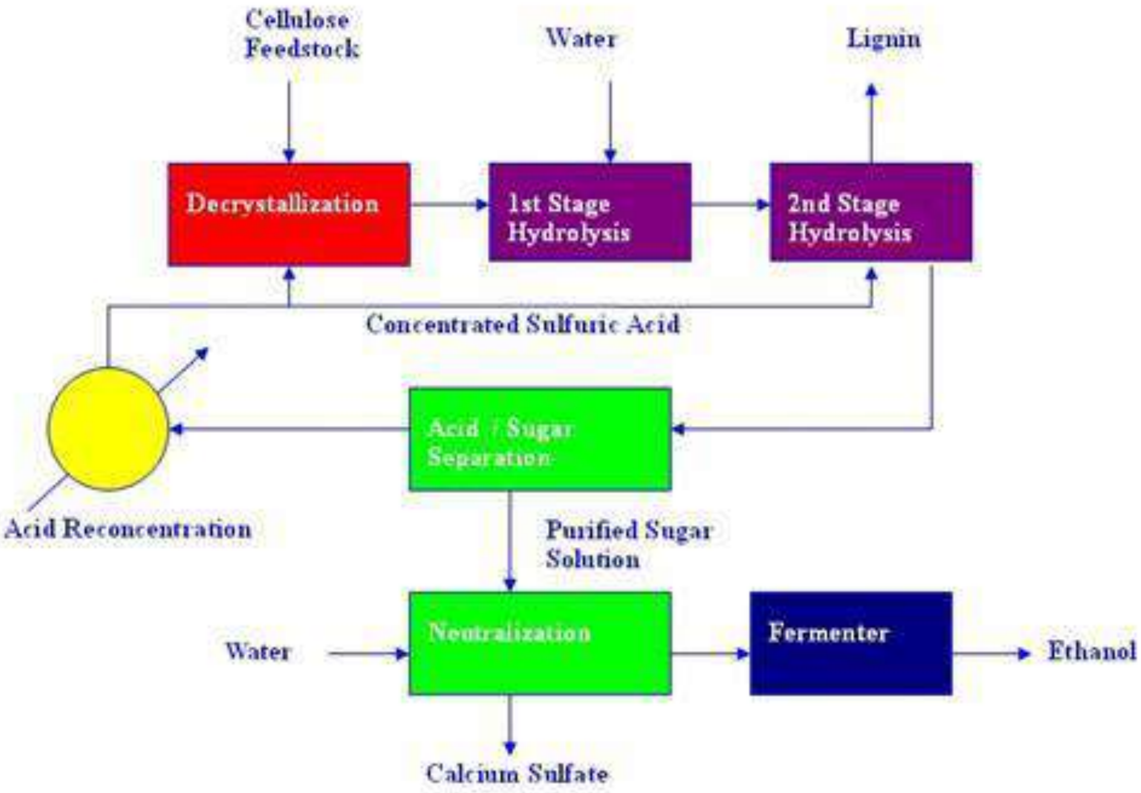


Fig. 7.28.2. Ethanol from wood by acid hydrolysis.

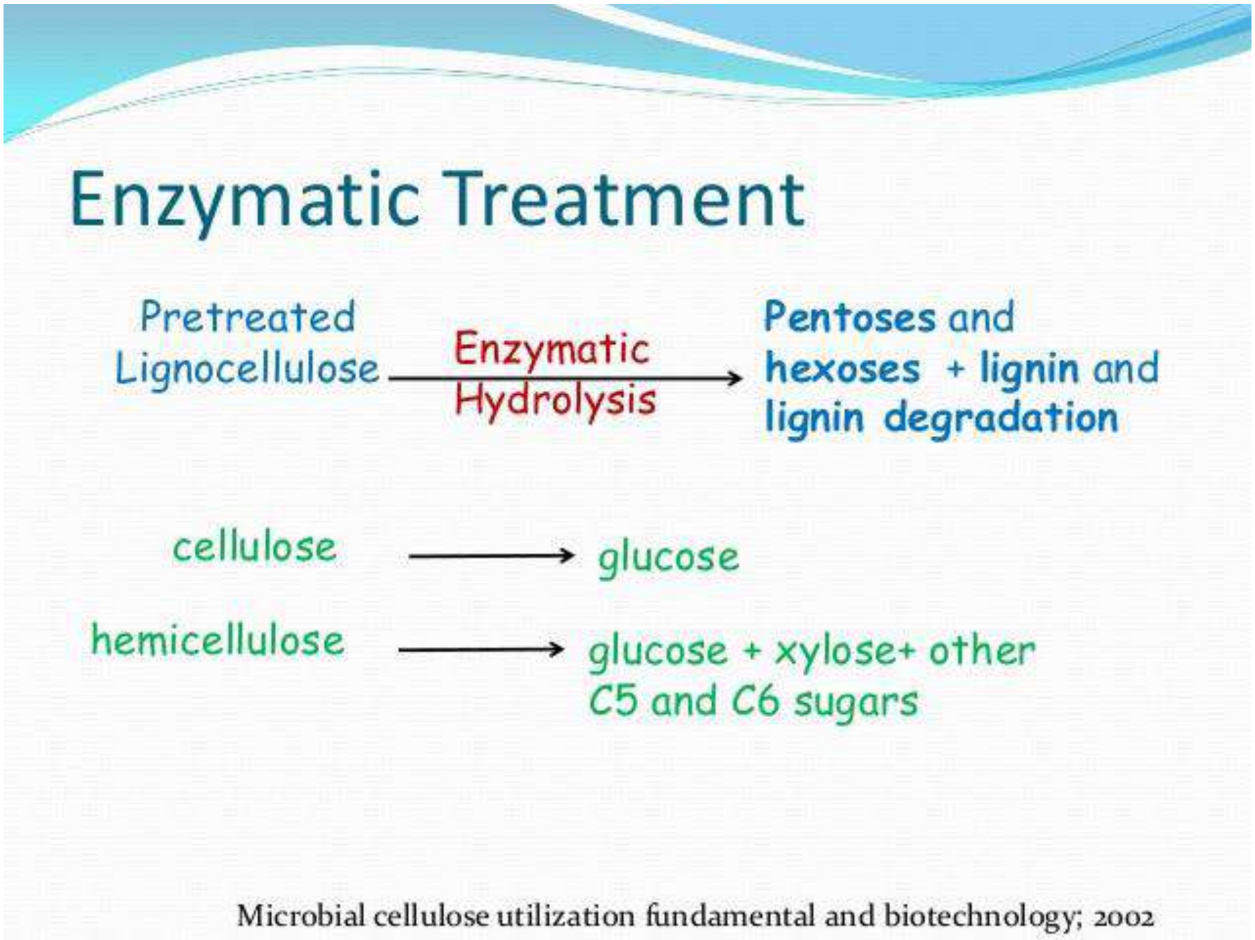
Dilute Acid Hydrolysis

- oldest, simplest yet efficient method
- hydrolyse the bio-mass to sucrose
- hemi-cellulose undergo hydrolysis with the addition of 7% of sulfuric acid under the temperature 190°C.
- to generate the more resistant cellulose portion, 4% of sulfuric acid is added at the temperature of 215°C



Enzymatic hydrolysis

Enzymatic hydrolysis is a process in which enzymes facilitate the cleavage of bonds in molecules with the addition of the elements of water. It plays an important role in the digestion of food. The enzymes are produced by growing a cellulase-producing organism inasubmergedculture,with cellulose or anothersuitablecarbohydrate as the primary source of carbon.



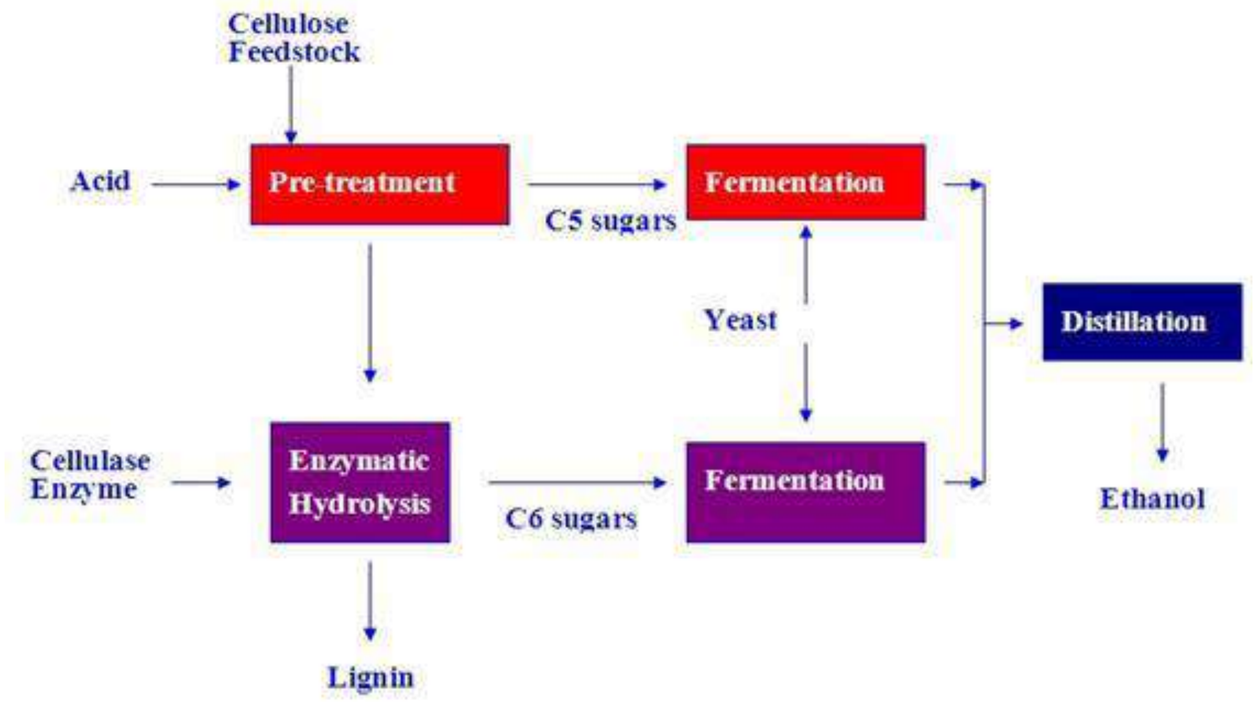
Enzymatic Treatment

Pretreated Lignocellulose $\xrightarrow[\text{Hydrolysis}]{\text{Enzymatic}}$ **Pentoses** and **hexoses** + **lignin** and **lignin degradation**

cellulose $\longrightarrow$ glucose

hemicellulose $\longrightarrow$ glucose + xylose+ other C5 and C6 sugars

Microbial cellulose utilization fundamental and biotechnology; 2002



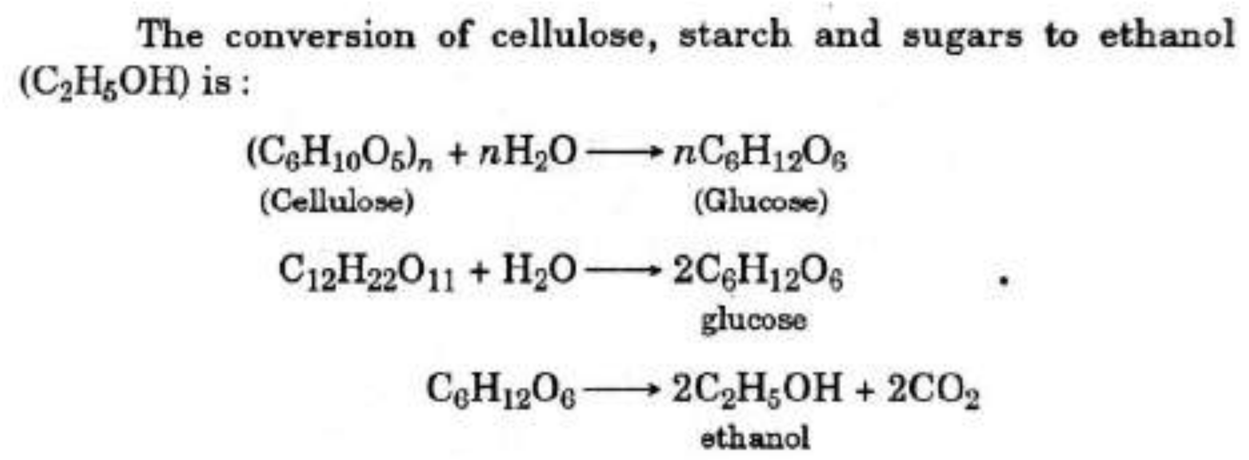
Acid hydrolysis can be carried out with dilute or concentrated acids. The important advantage of concentrated acid hydrolysis is that, since it is carried out at low temperatures, the sugars formed are not degraded. However, the large quantity of acid needed to wet the feedstock cannot be discarded. Acid recovery is thus necessary, and thisisaevery expensive operation. As a result, virtually all recent development work has been with dilute acids. Pretreatment of feedstock is not as critical for acid hydrolysis as it is for other conversion methods. With wood, size reduction to chips is generally sufficient.

Advantage Acid hydrolysis

When compared with enzymatic hydrolysis processes and direct conversion technologies, acid hydrolysis has many advantages. It has been much more extensively studied and practiced at all levels, from the laboratory to commercial operations. Also, the use of wood as feedstock introduces no technical problems and does not require extensive pretreatment. Another advantage is that asepsis is not an important issue for the acid hydrolysis unit operation. Finally, it has much shorter reaction time than enzymatic hydrolysis. The acid catalyst is cheap and readily available. No expensive enzyme production facilities are necessary.

Disadvantage Acid hydrolysis

Acid hydrolysis has a lower potential yield of ethanol than enzymatic hydrolysis or direct conversion. Because of lower yields, the potential sugar concentration is lower than that of form enzymatic hydrolysis. Also, the by-product, lignin, is of lower potential market value than that from enzymatic hydrolysis. Another problem is that the more severe operating conditions acids combined with high temperatures-cause corrosion and require expensive construction materials. Metals from the reactor can have an inhibitory effect on the hydrolysis reaction, thereby decreasing the fermentable sugar yield.



The conversion of cellulose, starch and sugars to ethanol (C_2H_5OH) is :

$$\underset{\text{(Cellulose)}}{(C_6H_{10}O_5)_n} + nH_2O \longrightarrow \underset{\text{(Glucose)}}{nC_6H_{12}O_6}$$

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow \underset{\text{glucose}}{2C_6H_{12}O_6}$$

$$C_6H_{12}O_6 \longrightarrow \underset{\text{ethanol}}{2C_2H_5OH} + 2CO_2$$

In batch fermentations, complete sugar consumption means long fermentation times and, hence, low average ethanol productivity by volume. With continuous stirred-tank fermenters, it is common to have the point of maximum ethanol productivity at a dilution rate as near to maximum as possible, leaving some residual sugar in the fermenter effluent.

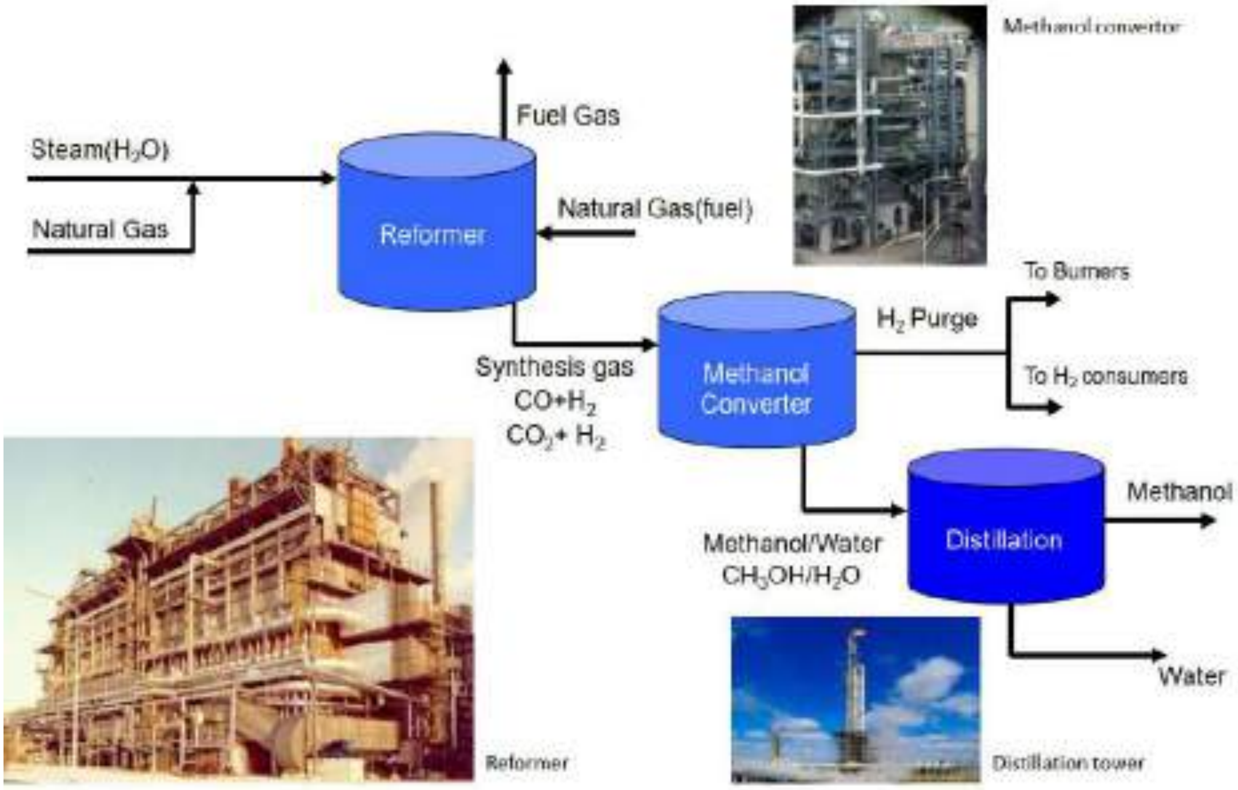
The choice of the best strategy is therefore a function of factors such as the type of raw material, cost and availability of distillation energy, available waste disposal options etc.

METHANOL PRODUCTION

It is also known as methyl alcohol, wood alcohol, wood naphtha or wood spirits .It has chemical formula CH_3OH (often abbreviated as MeOH) It is a light, volatile, colourless, flammable, liquid with a distinctive odour. At room temperature it is a polar liquid.

Boiling point: 64.96° C (148.93° F), Freezing point: -93.9°C (-137°F), Relative Density: 0.8, Methanol is also a toxin and should not be ingested. Drinking quantities of methanol can result in blindness and severe damage to the central nervous system.

Methanol is the most flexible chemical commodities and energy sources available today, as it can be made from a wide array of feedstocks.Methanol is produced from synthesis gas, which has carbon monoxide (CO) and hydrogen gas as its main components. An important advantage of methanol is that it can be made from any resource that can be converted first into synthesis gas. Through gasification; synthesis gas can be produced from anything that is or ever was a plant. This includes biomass, agricultural and timber waste, solid municipal waste, and a number of other feed stocks.



Natural Production of Methanol

In a typical plant, methanol production is carried out in two steps. The first step is to convert the feedstock natural gas into a synthesis gas stream consisting of carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and hydrogen. This is usually accomplished by the catalytic reforming of feed gas and steam. Partial oxidation is another possible route. The second step is the catalytic synthesis of methanol from the synthesis gas. Each of these steps can be carried out in a number of ways and various technologies offer a spectrum of possibilities which may be most suitable for any desired application.

During synthesis the following reactions occur:

$$CO + 2H_2 \rightarrow CH_3OH \quad \ldots\ldots\ldots\ldots\text{(i)}$$

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_20 \ldots\ldots\text{(ii)}$$

$$CO_2 + H_2o \rightarrow CO + H_2 \ldots\ldots\ldots\ldots\text{(iii)}$$

All three equilibrium reactions occur simultaneously, although it is common to only consider two of the three to simplify any analysis, as it can be seen that Equations (ii) and (iii) combined are the same as Equation (i). Direct oxidation of Methane:

$$2CH_4 + O_2 \rightarrow 2CH_3OH$$

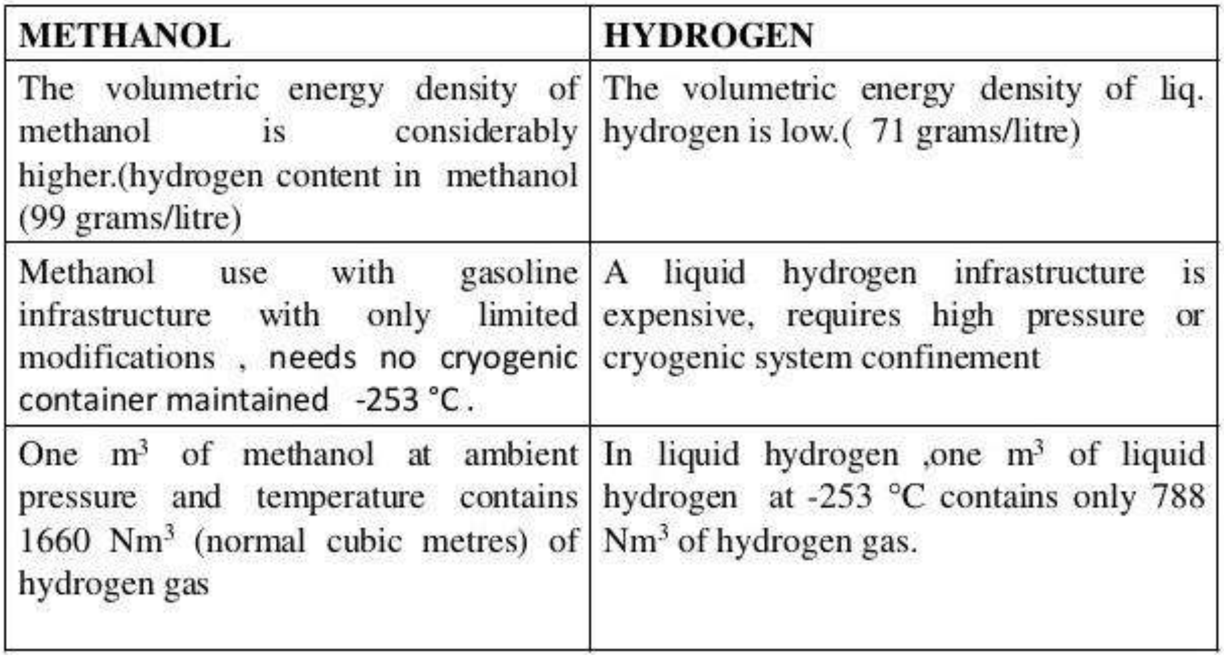
ADVANTAGES OF METHANOL

Methanol is a liquid under normal conditions, allowing it to be stored, transported and dispensed easily, like gasoline and diesel fuel. It can also be readily transformed by dehydration into dimethyl ether, a diesel fuel substitute with a cetane number of 55. Methanol, being totally soluble in water, rapidly diluted to a concentration to start biodegradation for microorganism. Methanol is used as raw material in chemical industry and denitrification in water treatment plants. Switching fuels from gasoline to methanol would reduce the incidence of fuel related fires by 90%.

ADVANTAGES OVER ETHANOL

The yield of Methanol generated from biomass is much greater than ethanol. Methanol made from organic materials using fisher's tropsch method of synthesis gas catalysis Methanol is used as mean energy storage, fuel and raw material. Methanol obtained from fossil fuels has a lower price than ethanol. Methanol is blended with gasoline like ethanol. In 2007, China blended more than 1 billion US gallons (3,800,000 m3) of methanol into fuel. M85, a mixture of 85% methanol and 15% gasoline as a fuel

ADVANTAGES OVER HYDROGEN



METHANOL	HYDROGEN
The volumetric energy density of methanol is considerably higher.(hydrogen content in methanol (99 grams/litre)	The volumetric energy density of liq. hydrogen is low.(71 grams/litre)
Methanol use with gasoline infrastructure with only limited modifications , needs no cryogenic container maintained -253 °C .	A liquid hydrogen infrastructure is expensive, requires high pressure or cryogenic system confinement
One m^3 of methanol at ambient pressure and temperature contains 1660 Nm^3 (normal cubic metres) of hydrogen gas	In liquid hydrogen ,one m^3 of liquid hydrogen at -253 °C contains only 788 Nm^3 of hydrogen gas.

DISADVANTAGES

High energy costs associated with generating hydrogen. Generation from syngas still dependent on fossil fuels. Energy density (by w/v) is one half of that of gasoline and 24% less than ethanol. Corrosive to some metals including aluminum, zinc and manganese. Pipelines designed for petroleum products cannot handle methanol. Thus methanol requires shipment at higher energy cost in trucks and trains, until a whole new pipeline infrastructure can be built.

Increases emissions of volatile organic compounds (VOCs) from fuel, which contributes to increased tropospheric ozone and possibly human exposure. Low volatility in cold weather: pure methanol-fueled engines can be difficult to start (use: M85). The gasoline allows the engine to start even at lower temperatures. Methanol is toxic. It is lethal when ingested in larger amounts (30 to 100 mL). It does not contain any carcinogens, but on metabolism in formaldehyde, which is toxic and carcinogenic.

Methanol creates a fire risk compared to hydrogen in open spaces. It is much safer than ethanol. It is more difficult to ignite, and releases less heat when it burns. Its fires can be extinguished with plain water, whereas gasoline floats on water and continues to burn.

Principles of Thermo chemical Conversion

Thermal conversion processes use heat as the dominant mechanism to convert biomass into another chemical form. Also known as thermal oil heating, it is a type of heating in which a liquid phase heat transfer medium is heated and circulated to one or more heat energy users within a closed loop system. Thermo chemical processes are most commonly employed for converting biomass into higher heating value fuels. Major thermal conversion route include direct combustion to provide heat, liquid fuel and other elements to generate process heat for thermal and electricity generation.

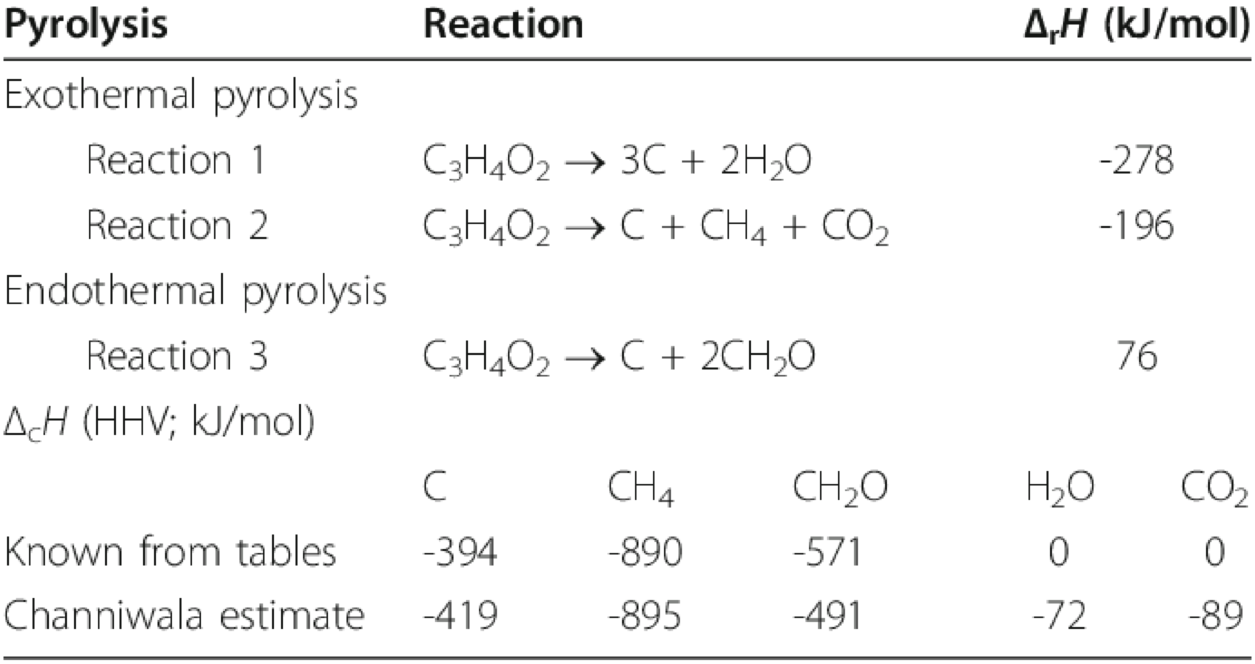
COMBUSTION

Combustion is defined as the exothermic reaction between fuel and oxygen to form mainly carbon dioxide and water vapors. Combustion is the process by which more than 90% of the world’s primary energy supply is realized in order to provide heat and energy services. It is estimated that in the developing world at least one and a half billion people fulfill their energy needs from wood, either as firewood or indirectly as charcoal. Biomass can also be co-combusted with coal in coal-fired plants.

PYROLYSIS

Pyrolysis is the process which converts biomass directly into solid (charcoal), liquid (bio oil), and gaseous (fuel gas) products by thermal decomposition of biomass in the absence of oxygen.

The relative amounts of the three co-products depend on the operating temperature and the residence time used in the process. Pyrolytic oil may be used directly as a liquid fuel for boiler, diesel engine, gas turbine for heat and electricity generation, or catalytically upgraded to transport grade fuels. In all thermo-chemical conversion processes, pyrolysis plays a key role in the reaction kinetics.



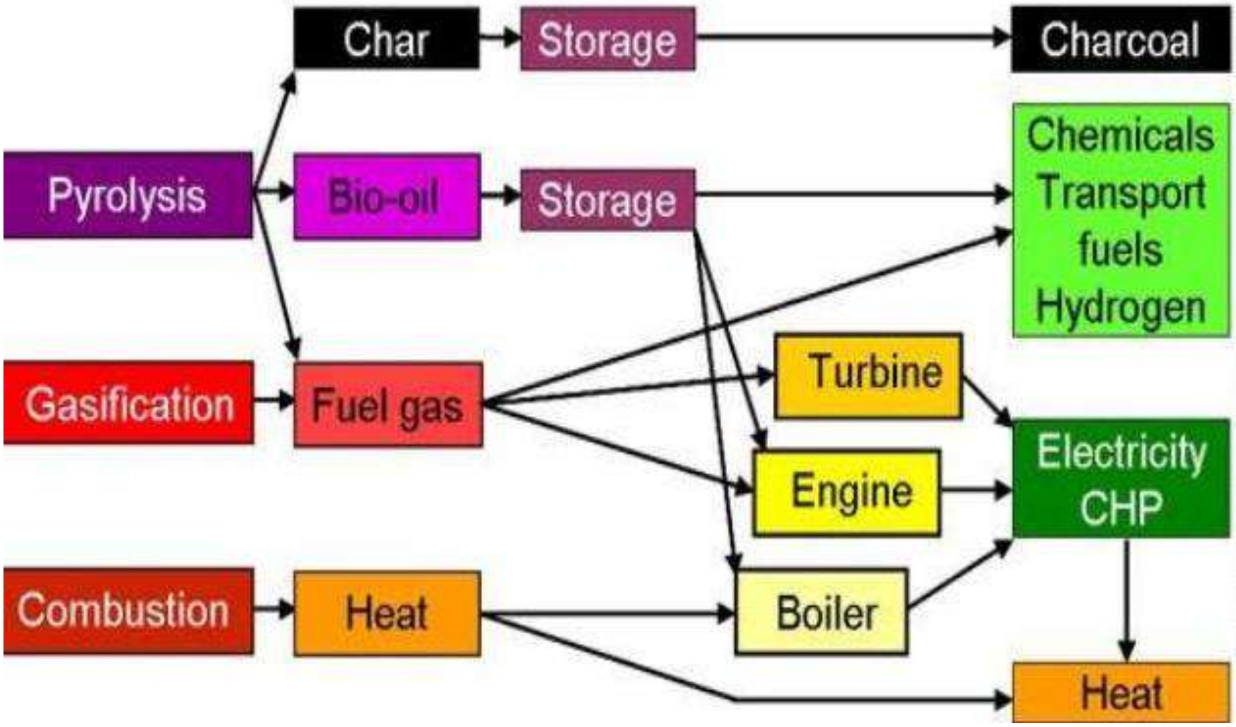
Pyrolysis	**Reaction**			**$\Delta_r H$ (kJ/mol)**	
Exothermal pyrolysis					
Reaction 1	$C_3H_4O_2 \rightarrow 3C + 2H_2O$			-278	
Reaction 2	$C_3H_4O_2 \rightarrow C + CH_4 + CO_2$			-196	
Endothermal pyrolysis					
Reaction 3	$C_3H_4O_2 \rightarrow C + 2CH_2O$			76	
$\Delta_c H$ (HHV; kJ/mol)					
	C	CH_4	CH_2O	H_2O	CO_2
Known from tables	-394	-890	-571	0	0
Channiwala estimate	-419	-895	-491	-72	-89

$\Delta_c H$, heat of combustion; HHV, higher heating value; $\Delta_r H$, reaction enthalpy.

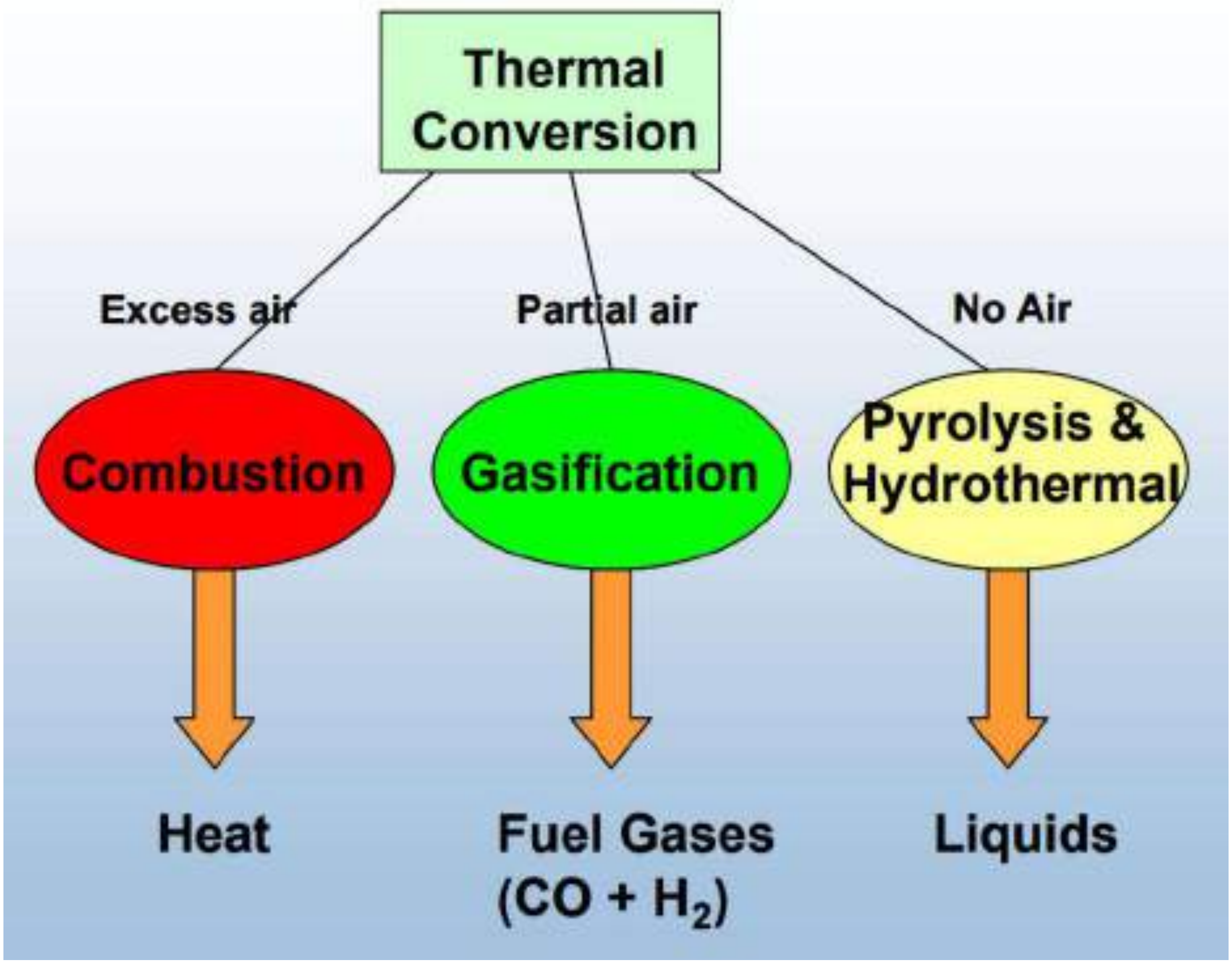
Combustion Reaction

$$\text{fuel} + O_2 \longrightarrow H_2O + CO_2$$

A reaction of a fuel with oxygen, producing energy in the form of heat and/or light



Char
Storage
Charcoal
Pyrolysis
Bio-oil
Storage
Chemicals
Transport
fuels
Hydrogen
Gasification
Fuel gas
Turbine
Engine
Electricity
CHP
Combustion
Heat
Boiler
Heat



Thermal Conversion

Excess air

Partial air

No Air

Combustion

Gasification

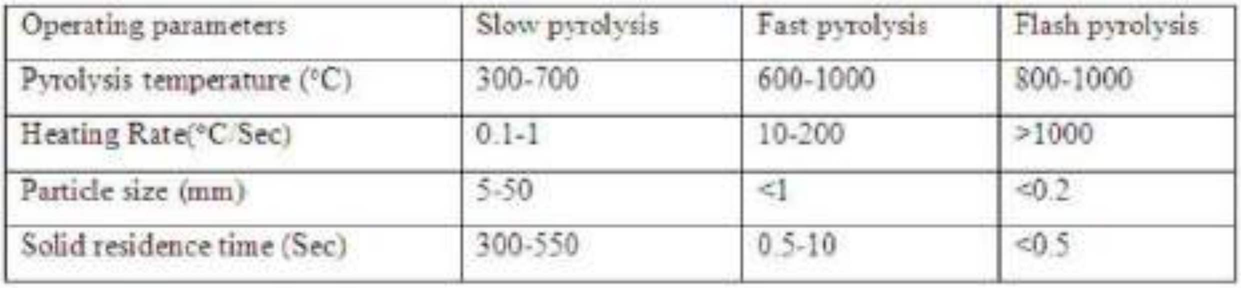
Pyrolysis & Hydrothermal

Heat

Fuel Gases $(CO + H_2)$

Liquids

Main operating parameters for Pyrolysis Process



Operating parameters	Slow pyrolysis	Fast pyrolysis	Flash pyrolysis
Pyrolysis temperature (°C)	300-700	600-1000	800-1000
Heating Rate(°C/Sec)	0.1-1	10-200	>1000
Particle size (mm)	5-50	<1	<0.2
Solid residence time (Sec)	300-550	0.5-10	<0.5

At present, the preferred technology is fast or flash pyrolysis at high temperature with very short residence time.

Slow pyrolysis

Slow pyrolysis is a conventional pyrolysis process whereby the heating rate is kept slow (approximately 0.1-1 ^{o}C/s). This slow heating rate leads to higher char yield than the liquid and gaseous products. Slow pyrolysis has been utilized for thousands of years primarily for the production of charcoal. In slow wood pyrolysis, biomass is heated to ~500 ^{o}C. The vapour residence time in the reactor, gas-phase products have ample opportunities to continue to react with other products to form char.25 – 30 % char yield.

Fast Pyrolysis

Fast pyrolysis uses much faster heating rates (about 10-200^{o}C/sec) and is considered as a better process than slow pyrolysis for producing liquid or gases. In fast pyrolysis the liquid product yield is higher since the fast heating rates allow the conversion of thermally unstable biomass compounds to a liquid product before they form undesired coke. Typically, fast pyrolysis processes produce 60-75 wt% of liquid bio oil, 15-20%wt of solid char and 10-20 %wt of non-condensable gases depending on the feed stock used.

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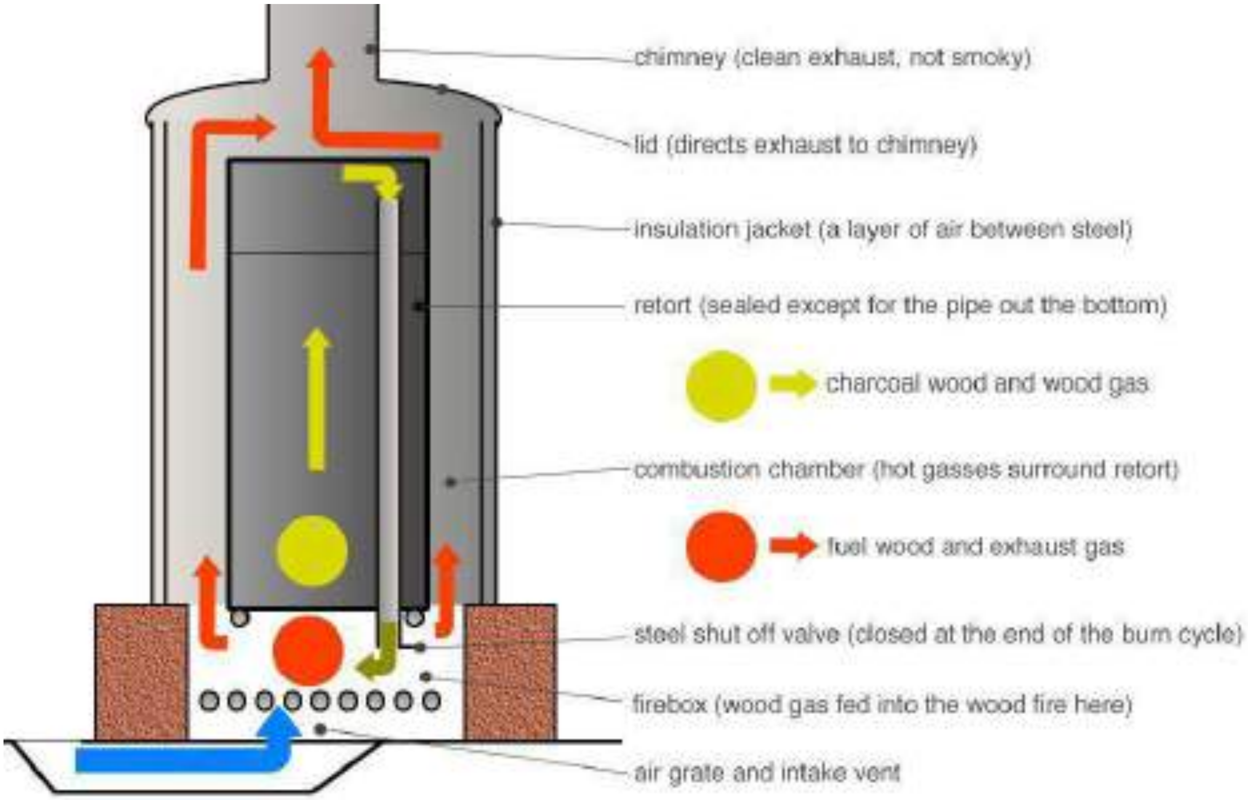


Charcoal Retort v2.0 - IslandBlacksmith.ca 2012

Flash pyrolysis

Flash pyrolysis is an improved version of fast pyrolysis, whereby the heating rates are very high, >1000°C/s, with reaction times of few to several seconds. Present reactors for flash pyrolysis include fluidized bed reactors, vacuum pyrolysis reactor, rotating cone reactor, entrained flow reactor, ablative, vortex or blade, twin screw reactors. Entrained flow or fluidized bed reactors are considered the best reactors for this purpose. Due to the rapid heating rates and short reaction times, for better yields, this process requires smaller particle size compared to the other processes.

Gasification

Gasification process is a process of conversion of solid fuel into gaseous fuel for wide applications. It produces gaseous fuels like H_2, CO,CH4,N2 of low calorific value. Biomass Gasification converts biomass into electricity and products, such as ethanol, methanol, fuels, fertilizers, and chemicals. In this operation feedstock is heated to high temperatures, producing gases which can undergo chemical reactions to form a synthesis gas.

Biomass is heated with no oxygen or only about one-third oxygen for efficient combustion; it gasifies to a mixture of carbon monoxide and hydrogen. Synthesis gas or syngas that has an energy content of 5 to 20 MJ/m^3 (depending on the type of biomass and whether gasification is conducted with air, oxygen or through indirect heating).This energy content is roughly 10 to **45%** of the heating value of natural gas. This whole process completed at elevated temperature range of 800– 1300 ◦C with series of chemical reaction that is why it come under thermo chemical conversion.

Gasification is made up for five discrete thermal processes:

I. **Drying**: The fuel wood pellets are heated and dried at the top of the gasifier unit. Moisture contained in the wood pellets is removed in this region to a level below 20%.

II. **Pyrolysis**: The dried wood pellets enter the second zone called the "Pyrolysis" zone. In this process gaseous products from devolatilization are partially burnt with the existing air.

III. C**ombustion**: 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.

IV. **Cracking**: In this zone Tar is breakdown into H_2, CO and flammable gases by exposure to high temp.

V. **Reduction**: In this region the hot gases formed in the above process is converted in to "Producer Gas" by the endothermic reactions.

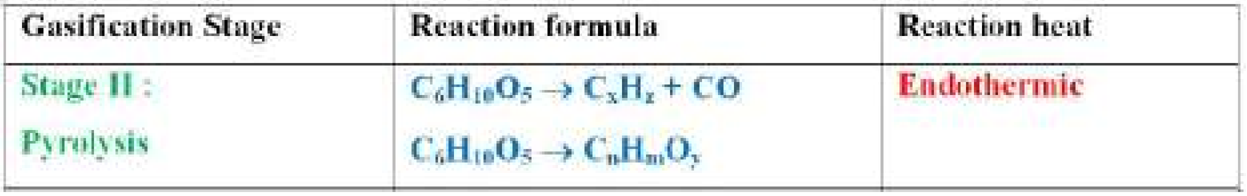
Gasification Process

Stage I.

Gasification process starts as auto-thermal heating of the reaction mixture. The necessary heat for this process is covered by the initial oxidation exothermic reactions by combustion of a part of the fuel.

Stage II.

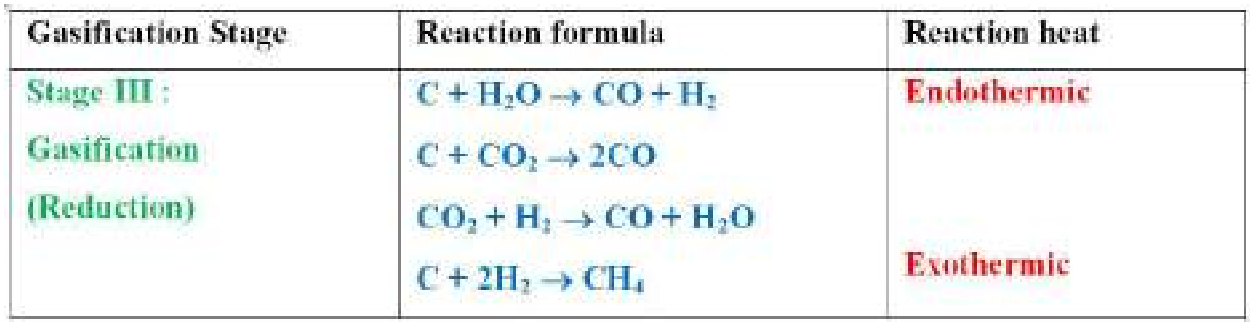
In the second - pyrolysis stage, combustion gases are pyrolyzed by being passed through a bed of fuel at high temperature. Heavier biomass molecules distillate into medium weight organic molecules and $C0_2$. In this stage, tar and char are also produced.



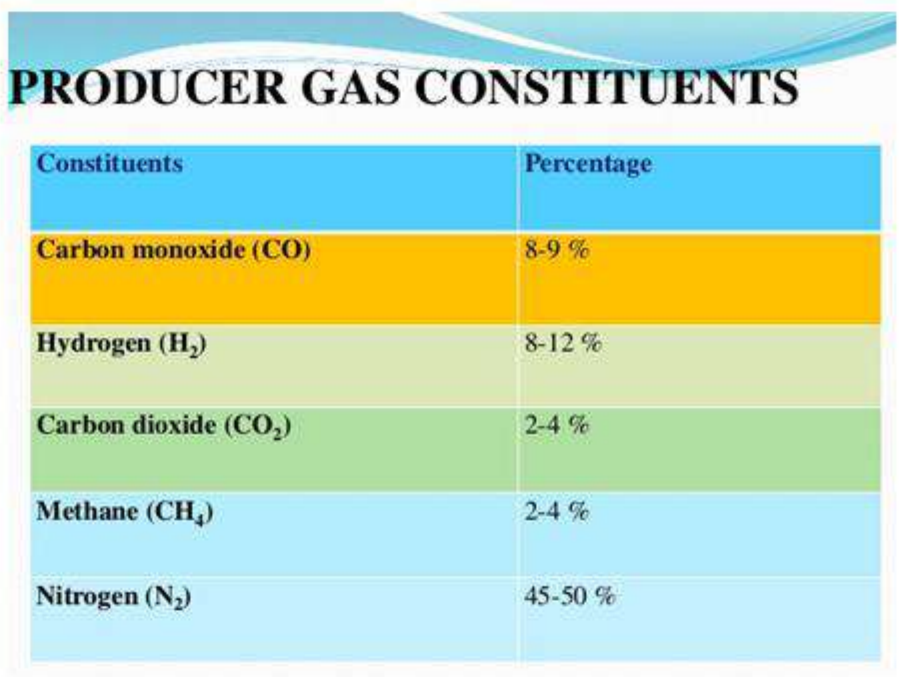
Gasification Stage	Reaction formula	Reaction heat
Stage II : Pyrolysis	$C_6H_{10}O_5 \rightarrow C_xH_z + CO$ $C_6H_{10}O_5 \rightarrow C_nH_mO_y$	Endothermic

Stage III.

Initial products of combustion, carbon dioxide (CO_2) and (H_2O) are reconverted by reduction reaction to carbon monoxide (CO), hydrogen (H_2) and methane (CH_4). These are the main combustible components of producer gas. These reactions, not necessarily related to reduction, occur at high temperature. Gasification reactions, most important for the final quality (heating value) of syngas, take place in the reduction zone of the gasifier. Heat consumption prevails in this stage and the gas temperature will therefore decrease. Tar is mainly gasified, while char, depending upon the technology used, can be significantly "burned", reducing the concentration of particulates in the product.



Gasification Stage	Reaction formula	Reaction heat
Stage III : Gasification (Reduction)	$C + H_2O \rightarrow CO + H_2$ $C + CO_2 \rightarrow 2CO$ $CO_2 + H_2 \rightarrow CO + H_2O$ $C + 2H_2 \rightarrow CH_4$	Endothermic Exothermic



PRODUCER GAS CONSTITUENTS

Constituents	Percentage
Carbon monoxide (CO)	8-9 %
Hydrogen (H_2)	8-12 %
Carbon dioxide (CO_2)	2-4 %
Methane (CH_4)	2-4 %
Nitrogen (N_2)	45-50 %

Classification of Biomass Gasifiers

Design of gasifier depends upon type of fuel used, air introduction in the fuel column and type of combustion bed. Two types:

Fixed Bed Gasifiers

a) Up-draught Gasifier

b) Down-draught Gasifier

c) Cross-draught Gasifier

Fluidized Bed Gasifiers

a) Circulating Fluidized

b) Bubbling Bed

FIXED BED GASIFIERS

The fixed bed type gasifier simply consisting of cylindrical reactor in which solid biomass fuel gasifying and produced gas move either upward or downward. These types of gasifier are simple in construction and generally operate with high carbon conversion, long solid residence time; low gas velocity and low ash carry over. Several type of fixed bed gasifiers were operating worldwide and further these can be classified according to the way in which primary air to gasify the biomass enters into the gasifier.

UPDRAFT GASIFIER

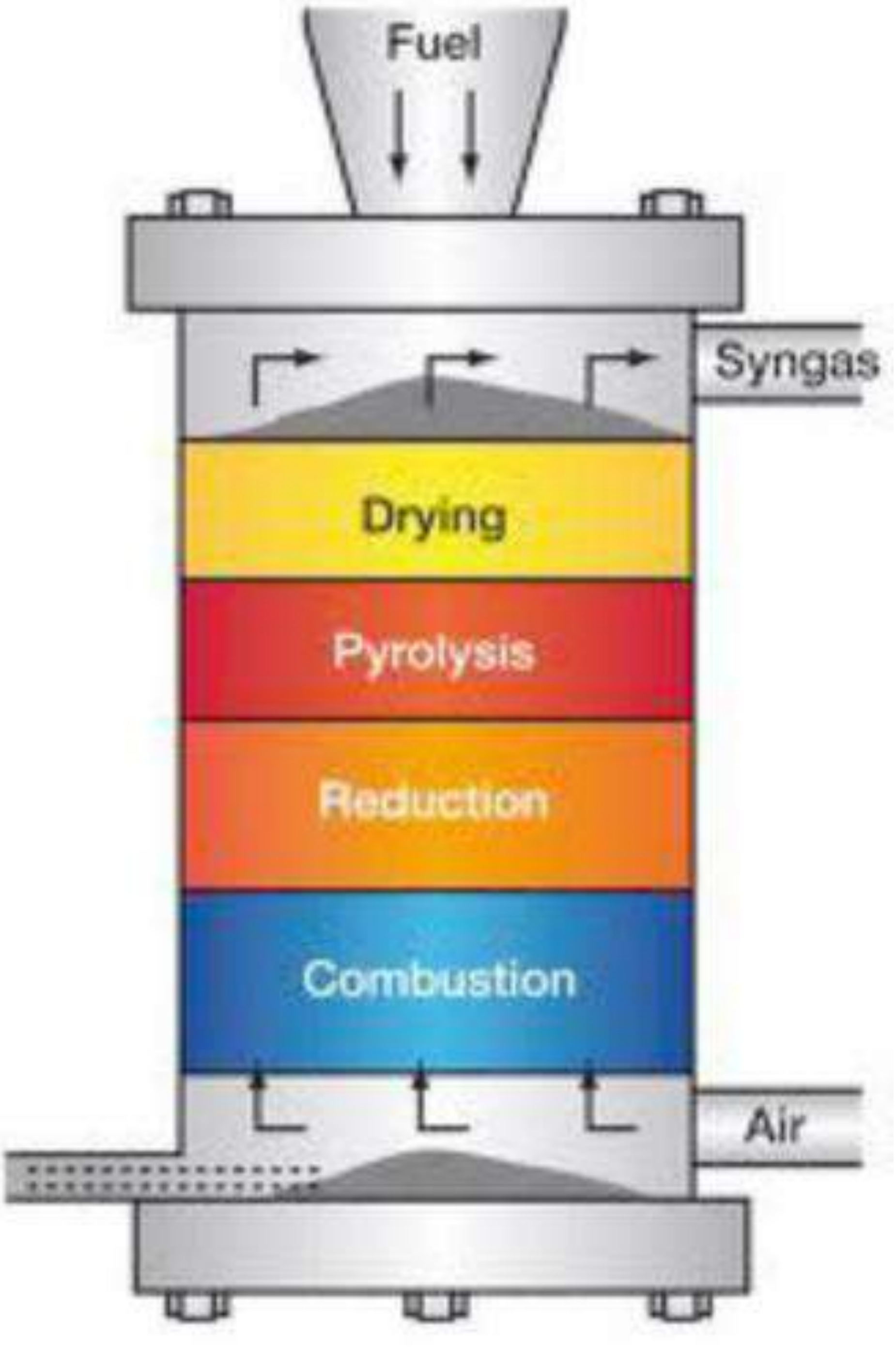
As the name indicates, air is introduced at the bottom and biomass at top of the reactor. A metallic grate is provided at the bottom of the reactor which supports the reaction bed. Complete combustion of char takes place at the bottom of the bed, liberating CO_2 and H_2O. These hot gases (~1000 ◦C) pass through the bed above, where they are reduced to H_2 and CO and cooled to 750 ◦C.Continuing up the reactor, the reducing gases (H_2 and CO) pyrolyze the descending dry biomass and finally dry the incoming wet biomass, leaving the reactor at a low temperature (~500 ◦C).The gas is drawn at upper side.

Updraft – Pros

High char conversion, as the char combustion occurs at the last stage of the process. The gasification efficiency is high due to high char conversion and due to that the gas exit temperature is relatively low (300-400°C). The gasifier construction is robust and relatively easy in operation. Good fuel flexibility [size variation, moisture up to 60%]

Updraft – Cons

As pyrolysis takes place at rather low temperature, tars production are significant. High capital cost


Fuel
Syngas
Drying
Pyrolysis
Reduction
Combustion
Air

DOWNDRAFT GASIFIER

In a downdraft gasifier, feedstock is introduced at the top and the gasifying agent is introduced through a set of nozzles located on the sides of the reactor. Reaction zones in a downdraft gasifier are similar to those in the updraft unit, except the locations of the oxidation and reduction zones are interchanged. The most important difference is that the pyrolysis products in the downdraft type are allowed to pass through the high temperature oxidation zone. Hence, they undergo further decomposition. Also, the moisture vaporized from the biomass enters the gasification zone and serves as a gasifying agent. The final product gases, which leave the gasifier from the bottom at a fairly high temperature (700oC), contain substantially less tar than the updraft gasifiers.

Downdraft – Pros

Very low tars, as the pyrolysis zone' temperature is high

Good gas quality

Modular design

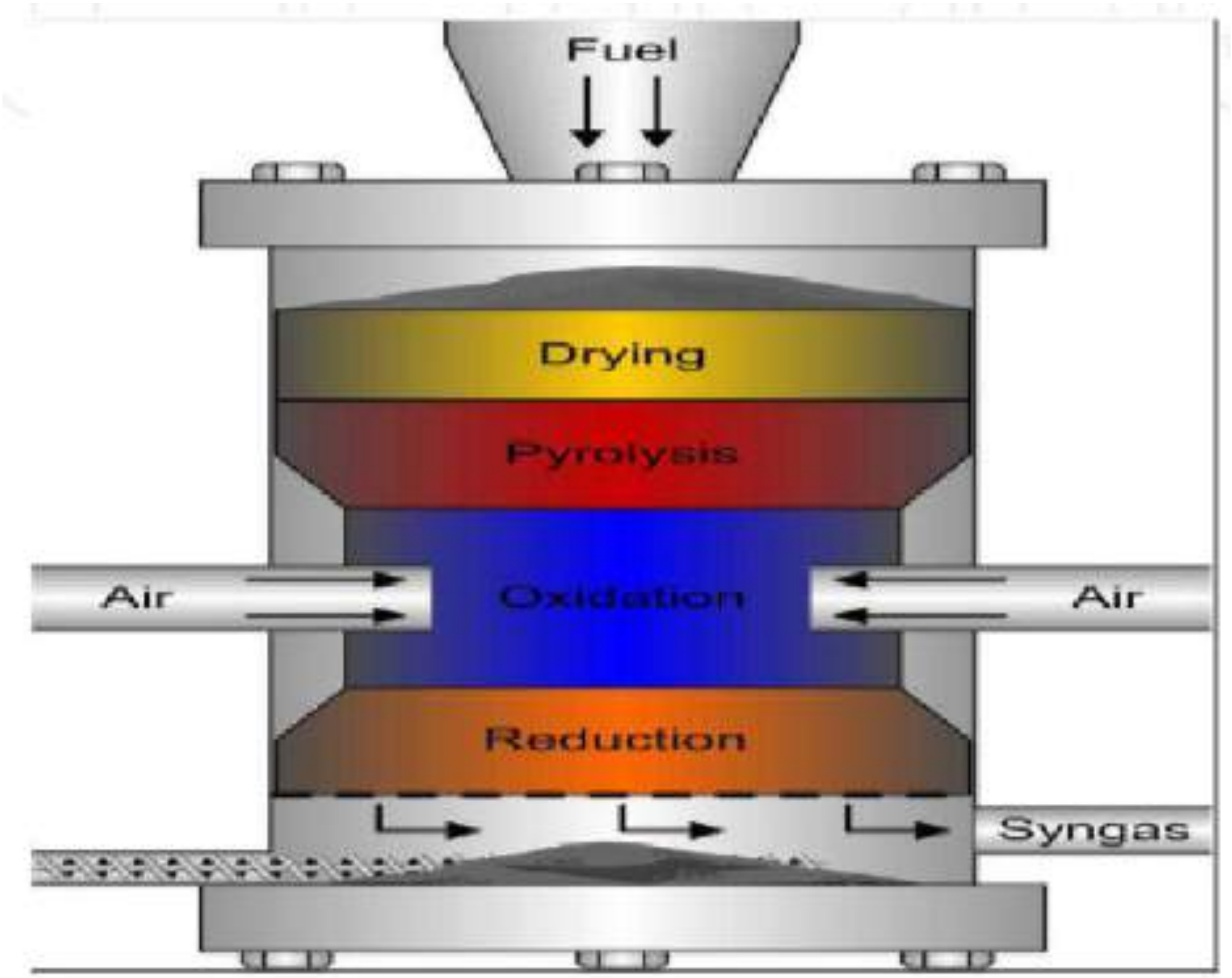
The gasifier construction and operation are simple

Good fuel flexibility [size variation, moisture up to 60%]

Downdraft – Cons

Limited scalability [0.5 MW / 500 kg/h]

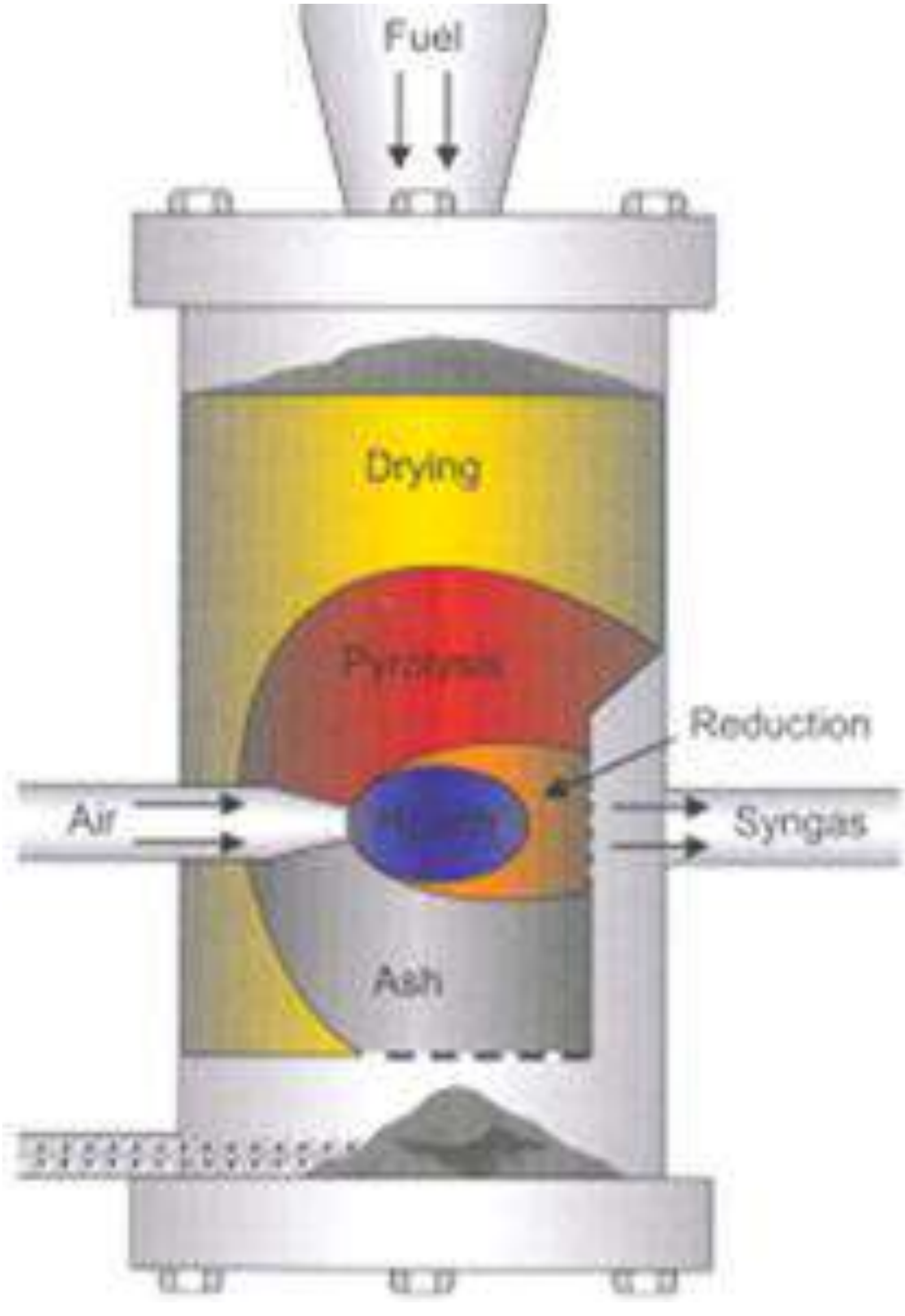
Precise fuel requirement [specific size, shape and moisture]



Cross-draft gasifiers

Cross-draft gasifiers exhibit many operating characteristics of the down draft units. Air or air/steam mixtures are introduced in the side of the gasifier near the bottom while the product gas is drawn off on the opposite side. Normally an inlet nozzle is used to bring the air into the center of the combustion zone . The velocity of the air as it enters the combustion zone is considerably higher in this design, which creates a hot combustion zone. The combustion (oxidation) and reduction zones are both concentrated to a small volume around the sides of the unit. Cross-draft gasifiers respond rapidly to load changes.

They are normally simpler to construct and more suitable for running engines than the other types of fixed bed gasifiers. However, they are sensitive to changes in biomass composition and moisture content.



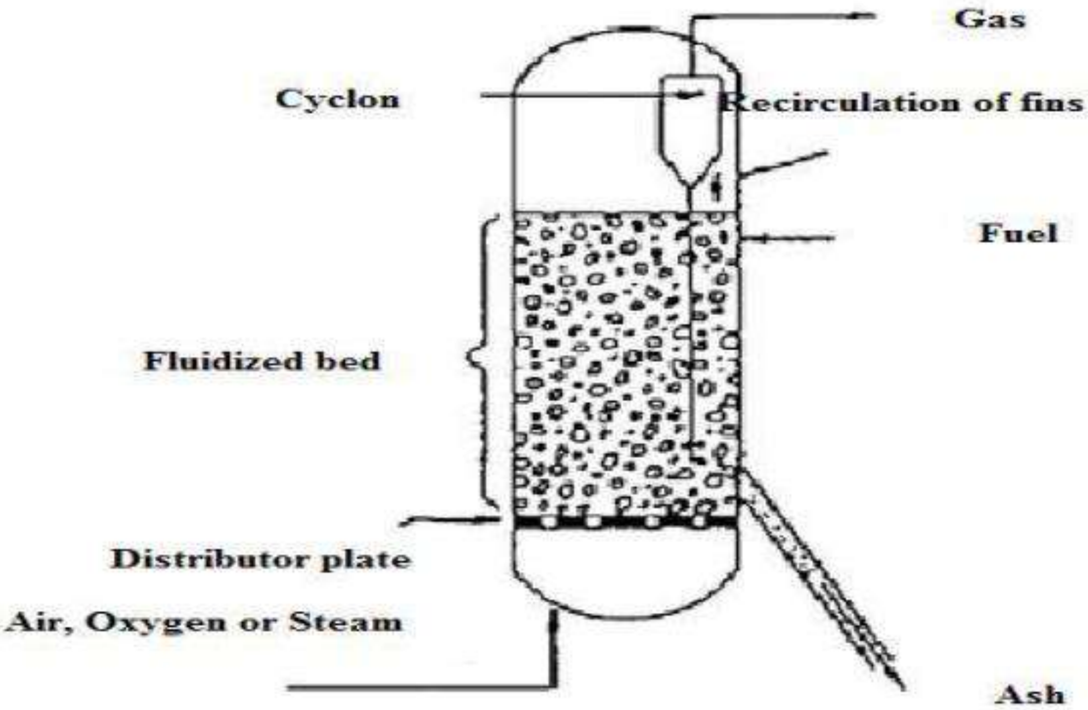
Fluidized bed gasifier

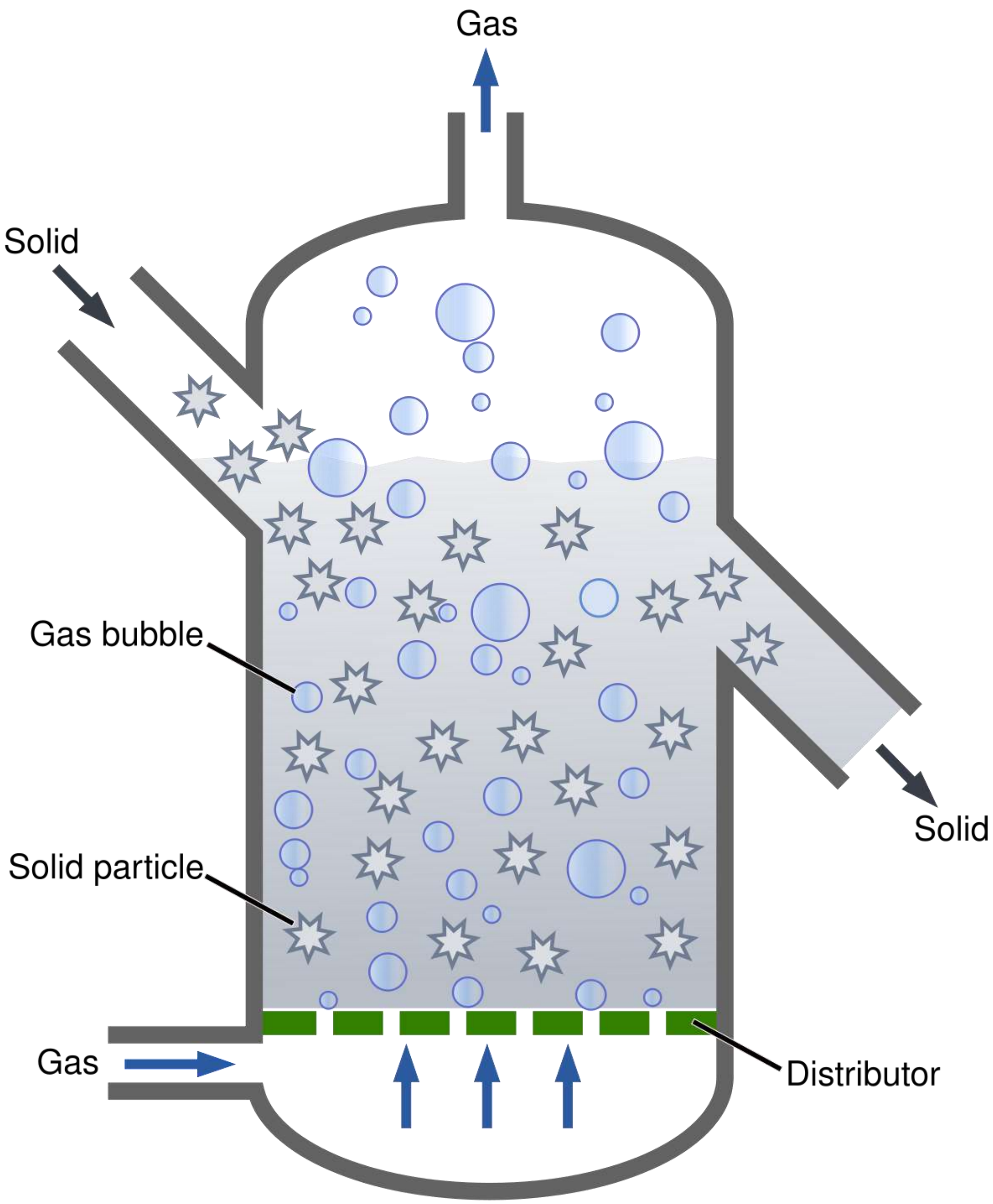
Fluidized bed (FB) gasification has been used extensively for coal gasification from many years, its advantage over fixed bed gasifiers being the uniform temperature distribution achieved in the gasification zone. In this type of gasifier, air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is 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. As a result of this treatment relatively large amount of gaseous materials produced. Further gasification and tar-conversion reactions occur in the gas phase. Ash particles are also carried over the top of the reactor.

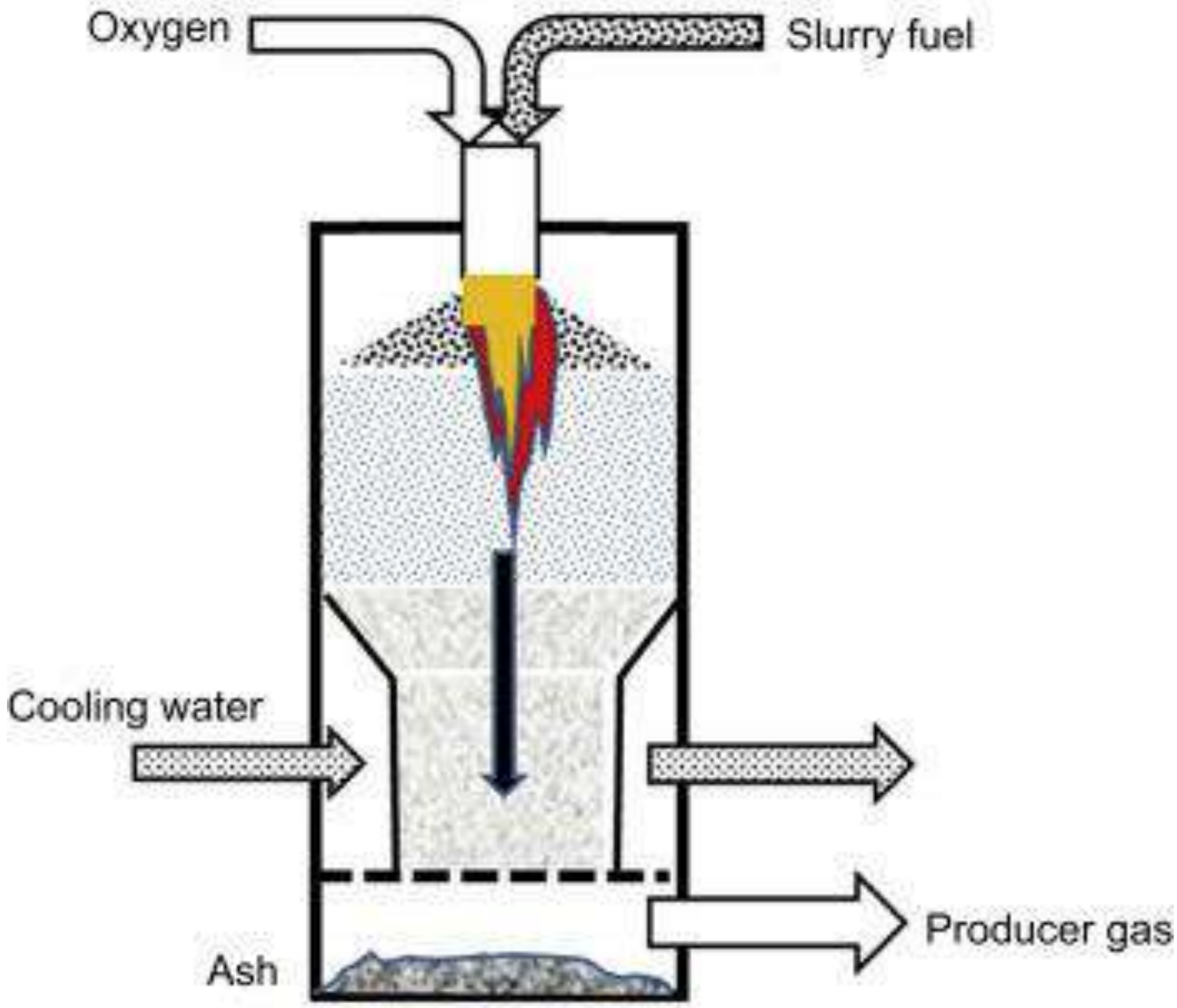
Entrained flow biomass gasifiers

This gasifier is a vertical, cylindrical vessel Dry pulverized solid fuel is combusted with oxygen in dense cloud of fine biomass particles in the gasifier top.Syngas exits from the bottom of the gasifier – it is routed through a cyclone (and a water scrubber) for the removal of fines. Operates at high temp. (1000-1800C) and high pressure (30-70 bars).Because of high temp. and pressure throughput is high and because of high temp. tar and methane are not present in the product gas. Oxygen requirement is higher than that for other types of gasifiers. Thermal efficiency is somewhat lower (the gas must be cooled before it can be cleaned with existing technology.

FLUIDIZED BED GASIFIR

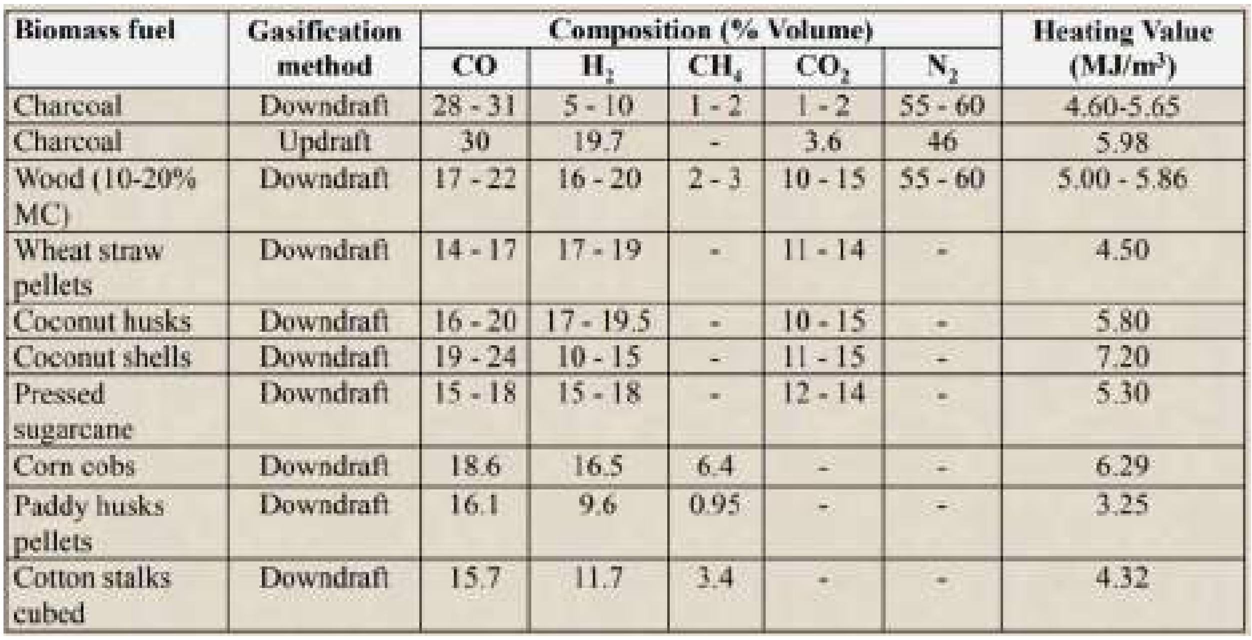



Gas
Solid
Gas bubble
Solid particle
Gas
Solid
Distributor



Plasma gasifiers

Municipal solid waste, biomedical waste, organic waste, hazardous wastes are gasified .Process of conversion of organic matter into synthetic gas and slag slag using plasma torch powered electric arc The torch ionizes gas and catalyzes organic matter into synthetic gas and solid waste – slag – Strong electric current under high voltage through the electrodes (vary from copper/tungsten to hafnium/ zirconium) forms an electric arc of 2,200 to 13,900 °C that ionizes pressurized inert gas (argon) – Waste is heated, melted and finally vaporized (dissociation and separation of complex molecules into atoms occur -plasma pyrolysis .Destruction of biomass is clean and clean alloyed slag from which metals can be recovered is produced – High temp. Prevents formation of toxic compounds (furans, dioxins, NOx, SOx, etc.) – Conversion rate of plasma gasification is >99%.



Biomass fuel	Gasification method	Composition (% Volume)					Heating Value (MJ/m³)
		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
Charcoal	Updraft	30	19.7	-	3.6	46	5.98
Wood (10-20% MC)	Downdraft	17 - 22	16 - 20	2 - 3	10 - 15	55 - 60	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
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Paddy husks pellets	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

Gas cleaning

Downdraught 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). Up draught gasifiers in engine applications have to be fitted with bulky and expensive tar separating equipment. It is however possible to get the gas from up draught gasifiers up to specification. Methods are under development to reform the gas in a high temperature zone (secondary gasification), in order either to burn or crack the tars. When suitable fuels are used, the gasifier and cleaner are well designed and the gasifier is operated above minimum capacity, tar contamination of the gas does not present a major problem. The major problem in producing an engine quality gas is that of dust removal. The amount of dust that is present in the producer gas at the outlet of the gasifier depends on the design of the equipment, the load of the gasifier and the type of fuel used.

The amount of dust present in the gas per m³ generally increases with the gasifier load, for the simple reason that higher loads give rise to higher gas velocities and more dust dragging.

Smaller fuel particles generally cause higher dust concentrations in the gas than do the larger fuel blocks. The type of fuel also has an influence: hardwoods generally generate less dust than softwoods. Maize cob gasification leads to severe dust contamination.

Wet purifiers such as water and oil scrubbers and bubblers are also effective but only within certain limits.The best cleaning effect are obtained by employing cloth filters. However, normal cloth filters are very sensitive to the gas temperature. In the case of wood or agricultural waste gasification, the dew-point of the gas will be around 70 C. Below this temperature water will condense in the filters, causing obstruction of the gas flow and an unacceptable pressure drop over the filter section of the gasification system. At higher temperatures normal cloth filters are likely to char and decompose in the hot gas stream. Another of their disadvantages is that they are subject to a rapid build-up of dust and so need frequent cleaning if not used in conjunction with a pre-filtering step.

The disadvantages of cloth filters can be partly offset by using woven glass wool filter bags. This material can be used at temperatures up to 300°C. By heating (insulated) filter housing by means of the hot gas stream coming from the gasifier, temperatures above 100°C can be maintained in the filter, thus avoiding condensation and enhanced pressure drop. If a pre-filtering step consisting of a cyclone and/or an impingement filter is employed. It is possible to keep the service and maintenance intervals within reasonable limits, i.e. cleaning each 100-150 h. This combination is probably the most suitable for small and medium-sized systems (up to 150 kW electric power), and experience has shown that engine wear is no greater than with liquid fuels. Electrostatic filters are also known to have very good particle separating properties, and most probably they could also be used to produce a gas of acceptable quality. However, such filters are expensive, and it is for this reason that their use is foreseen only in larger installations, i.e. equipment producing 500 kW electric powers and more.

Gas cooling

Generator gas coolers come in three broad categories: natural convection coolers, forced convection coolers and water coolers. Natural convection coolers consist of a simple length of pipe. They are simple to use and clean and require no additional energy input. They can be rather bulky, though this problem can be partly offset by using fined pipe in order to increase the conductive surface. Forced convection coolers are equipped with a fan which forces the cooling air to flow around the gas pipes. This type of cooler can be much smaller than the natural convection coolers. Its disadvantages are the extra energy input to the fan and the necessity to use gas cooling pipes of small diameters, which can lead to fouling problems. Water coolers are available in two types, the scrubber and the heat exchanger; where a water scrubber or bubbler is used, the objective is generally to cool and clean the gas in one and the same operation. Scrubbers of many different types exist, but the principle is always the same: the gas is brought in direct contact with a fluid medium (generally water) which is sprayed into the gas stream by means of a suitable nozzle device. The advantage of this system is its small size. Disadvantages are the need for fresh water, increased complexity of maintenance, and some power consumption resulting from the use of a water pump.

Utilization

Most gasifiers in commercial operation today are used for the production of heat, rather than fuel for internal combustion engines, because of the less stringent requirements for gas heating value and tar content. The fundamental advantage of a gasifier close coupled to a burning system is its ability to produce higher temperatures than can be achieved with conventional grate, combustion, liable to slagging problems at such temperatures, and in consequence its enhancement of boiler efficiency and output.

The most potential users of low-calorific fuel-gas in the future are expected to be found among the following industries: metallurgy, ceramic, cement, lime and pulp. In these industrial branches the conversion of kilns, boilers and driers from oil to fuel gas operation is in principal a quite simple operation.

Gasifiers connected to stationary engines offer the possibility of using biomass to generate mechanical or electrical power in the range from a few kW up to a few MW.Producer gas of engine quality needs a sufficiently high heating value (above 4200 Kj/m^3), must be virtually tar and dust free in order to minimize engine wear, and should be as cool as possible in order to maximize the engine's gas intake and power output.

Burner (stove, boiler, furnace, co-firing)

IC engine

Gas engine

Gas turbine

Combined processes (CHP, IGCC)

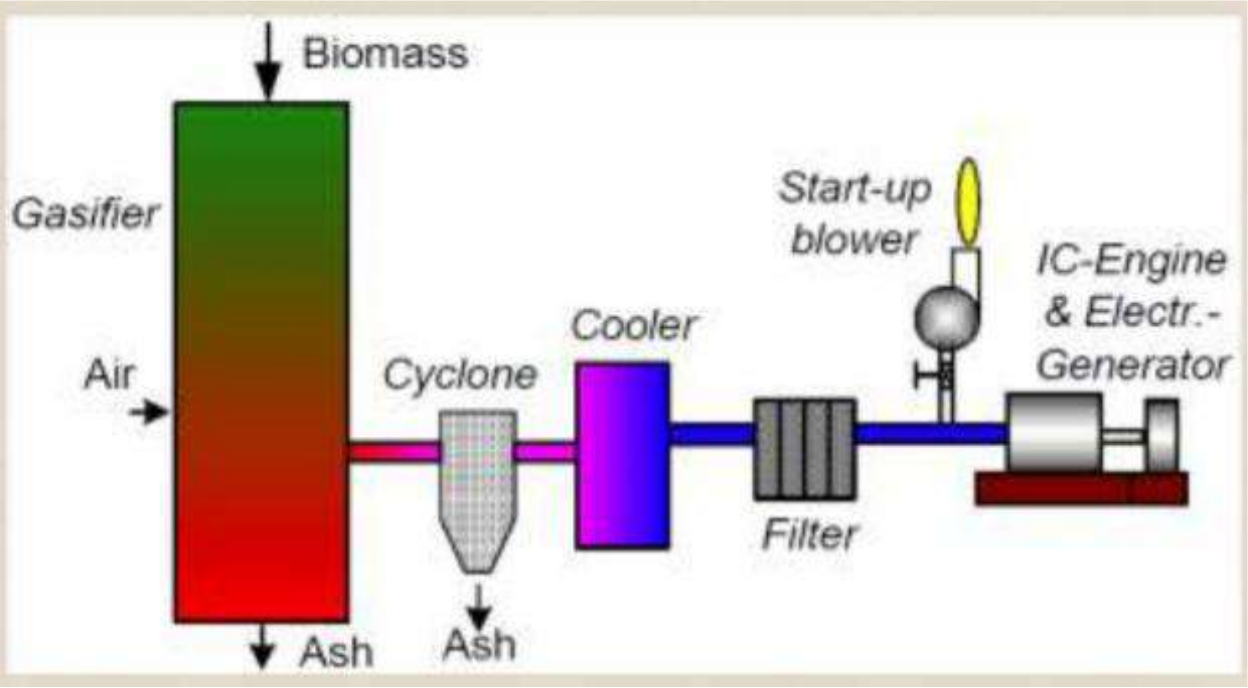
Fuel cell

ADVANTAGES OF GASIFICATION

Provides Sustainable & Affordable alternative to fossil fuel based power plants at low power levels. This technology can assure 'Continuous power supply' even at 'Peak load conditions'. Efficiency of the system is very high when compared to other Renewable energy systems such as Wind and Solar. Gasification is Eco-Friendly as it is "CO_2 Neutral", generates very little SO_2 & Nitrogen Oxides compared to conventional fossil fuel based power plants. It is a cost effective solution as it combines 'Low Unit Capital Cost' with 'Low Unit Cost of Production'. Cost of installation per kWe is about the same as for large power levels. Economic, Social and Environmental benefits associated with Biomass make it as an attractive renewable energy option.

DISADVANTAGES OF GASIFICATION

Gasification is a complex and sensitive process. Gasifiers require at least half an hour or more to start the process. Getting the producer gas is not difficult, but obtaining in the proper state is the challenging task. The physical and chemical properties of producer gas such as energy content, gas composition and impurities vary time to time. Some amount of tar is released in the gas. All the gasifiers have fairly strict requirements for fuel size, moisture and ash content. Inadequate fuel preparation is an important cause of technical problems with gasifiers.



UNIT V

ENERGY AND ENVIRONMENT

Improved Wood Burning Stove

In India, 80 per cent of total population lives in villages. The major energy demand of rural population is for cooking which contributes to about 98 per cent of their total energy consumption. Wood, agricultural waste and biomass are used as fuel in rural kitchen. The cooking appliances which are commonly used in rural houses have very low thermal efficiency (10 to 15 per cent) and hence per capita energy consumption in rural areas is much higher than that in urban areas.

Conventional stoves waste a lot of energy and pose many pollution hazards. Most traditional stoves can utilize only 2 – 10 per cent of the energy generated by the fuel. Black smoke emission consists of particles of sizes upto 5 microns , CO, CO2, oxidesofnitrogenand sulphur, hydrocarbons, aldehydes, ketones etc.,. These pollutants are detrimental to the environment and to the health of rural women. It causes headache, watery eyes, common cold and sneezing. Conventional stoves (chulha) take more time for cooking, more difficult to fire and consume more fuel.

The growing gap between the availability and demand for fire wood, poor thermal performance and pollution caused by traditional stoves forced the technologists to concentrate their attention on improving the thermal efficiencies of stoves. The adoption and large scale propagation of improved stoves would help in improving the health of rural women and in making more efficient resource utilization. This will also stop the large scale denudation of forest cover in the developing countries, and in arresting the large scale climatologically changes.

Improved Stoves

The traditional wood stoves are having a lot of drawbacks and the problem of insufficient and incomplete burning of wood in the traditional wood stove get rectified in these improved wood stoves. These improved stoves are also producing less smoke so they are polluting the environment in less quantity than the traditional wood stoves.

The improved wood stoves are more advantageous than the traditional wood stoves some of the advantages are given below

1)Smokeproduction
2)Fuelutilization
3)Heattransfer
4)Heatlosses
5) Efficiency

Stove Components

The improved wood stoves are having different components which make them more efficient. The different components of the improved wood stove are discuss below-

1)Firebox
2)AirInlet
3)Grate
4)Baffles

5)Dampers
6)Chimney
7)Cowl
8) Tunnel

1) Fire box

It is an enclosed space in which the initial combustion takes place and the fuel is burned. The energy required for the stoves to operate is released here. Most of the stoves contain only one fire box. But in some cases there may be a secondary fire box, which in turn will burn the gases produced by initial combustion. The efficiency of the stove depends on the efficiency of combustion in the fire box. It should be spacious enough to accommodate the fuel and pots commonly used for cooking and facilitate roasting of chapattis and charcoal. Fuel burnt in the presence of oxygen in the form of air entering the fire box and heat is ensured in the initial stage by kindling the fuel.

The firebox should be such that there is enough provision for entry of air so that oxygen in requisite quantity is available. Primary oxygen enters through the fuel feeding door of fire box and moves through the wood arranged in criss-cross manner. It also enters through the grate from the underneath if firebox has a grate on which the fuel rests. Secondary air is also necessary and mixes with volatiles and leads to complete combustion of fuel.

2) Air Inlet

Air is introduced inside the fire box by the air inlet. This air passesthroughthefuelbyadraft created by the chimney. An efficient stove should have an adjustable opening to allow the cook to control the rate of air, so as to control the burning and there by the temperature.

3) Grate

A frame of metal bars or other material for holding the burning fuel is a grate. This increases the efficiency by improving the access of airandimprovingtherateofcombustion. It is shown that if grate is used, the walls of the combustion chamber must slope towards the grate and that the areas of the grate open to the passage of air must be approximately 25 to 30% of the total grate area.

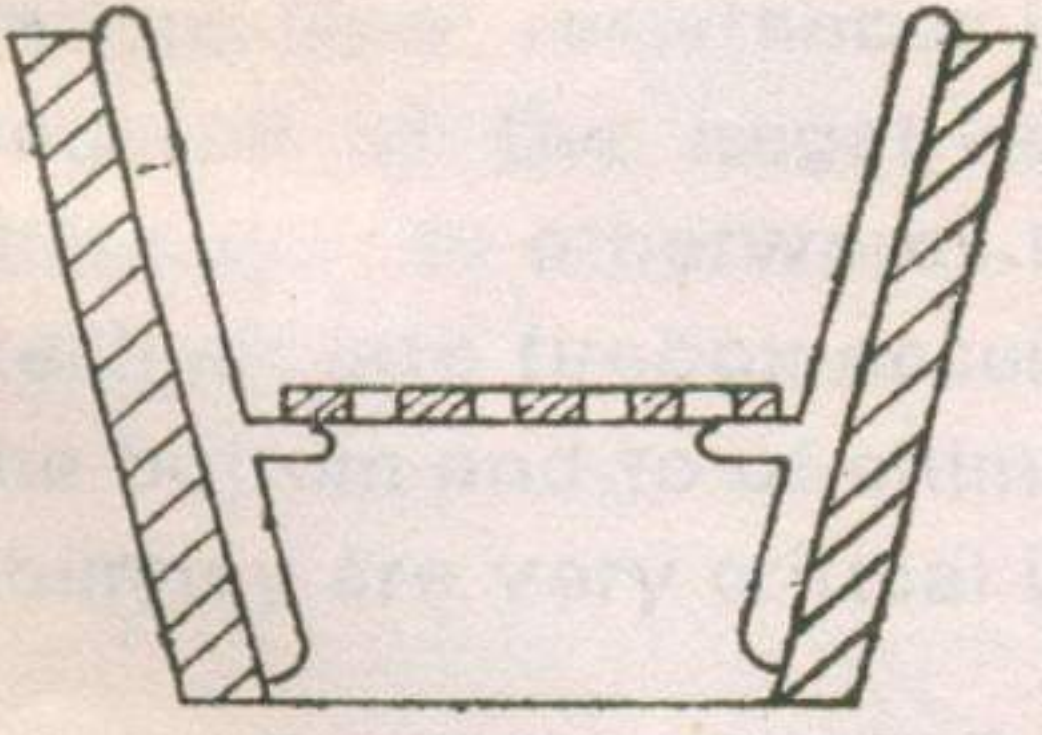


FIG.2. GRATE

4) Baffles

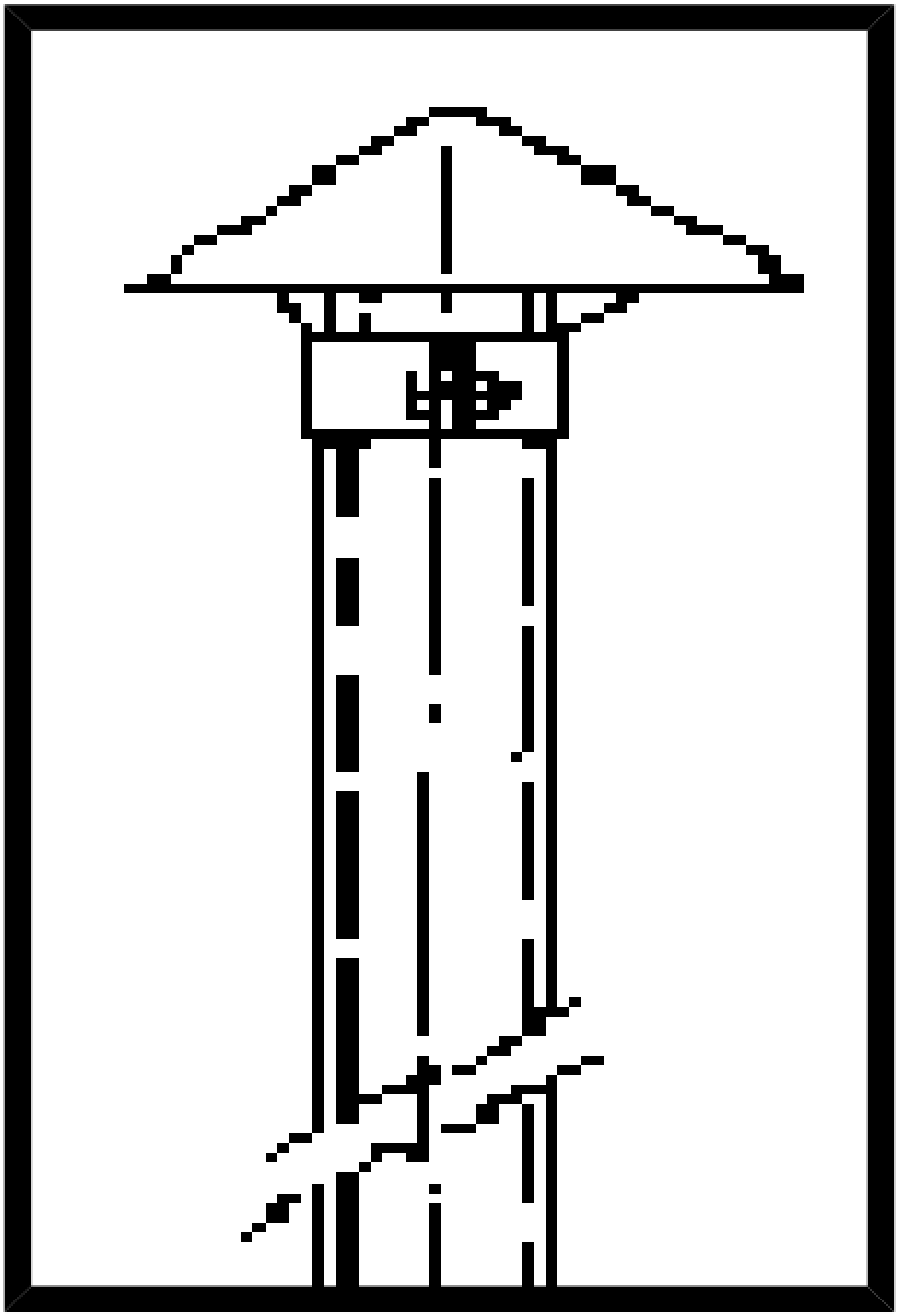
Baffles are the projections in the fuel passage. They are used in order to prevent direct escape of hot gases, allowing them to burn more completely. This also redirects the flow of hot gases around the pot, facilitating adequate heat transfer. When baffles are placed at the exit of the combustion chamber, they redirect the flame and gases back onto the surface of the wood, as well as to the pot surfaces facing the fire bed, thereby accelerating the cooking process.

5) Dampers

A movable plate which controls the draught is damper. It is made of metal sheet, and a handle of poor conductive material must be provided to avoid touching the heated material. The number of dampers used depends on the design characteristics.

6) Chimney

It is the pipe made either of asbestos, cement or clay or metal that is fixed to the rear end of a closed chulha and taken out either through the roof or wall and provided with a cap called cowl. It is an integral part of closed chulha design essentially provided to create draught to draw fresh air from the environment into the combustion chamber and to overcome various flow resistances in the stove. The draught occurs because of the negative pressure created at the base of chimney. The chimney should be taken out of the roof vertically as far as possible. The chimney should be cleaned at regular intervals with a sandbag to ensure better performance of chulha and soot should be removed from base of the chimney. The diameter of the pipe may be 3 inch or 7.5 cm. It should be given support by using clamps.



7) Cowl

Cowl is made of either with metal or red earth attached to the topofthechimneywhich offers protection against rain and improves the draught. An efficient chimney cap or cowl made of scrap metal is one which increases the draught regardless of wind direction

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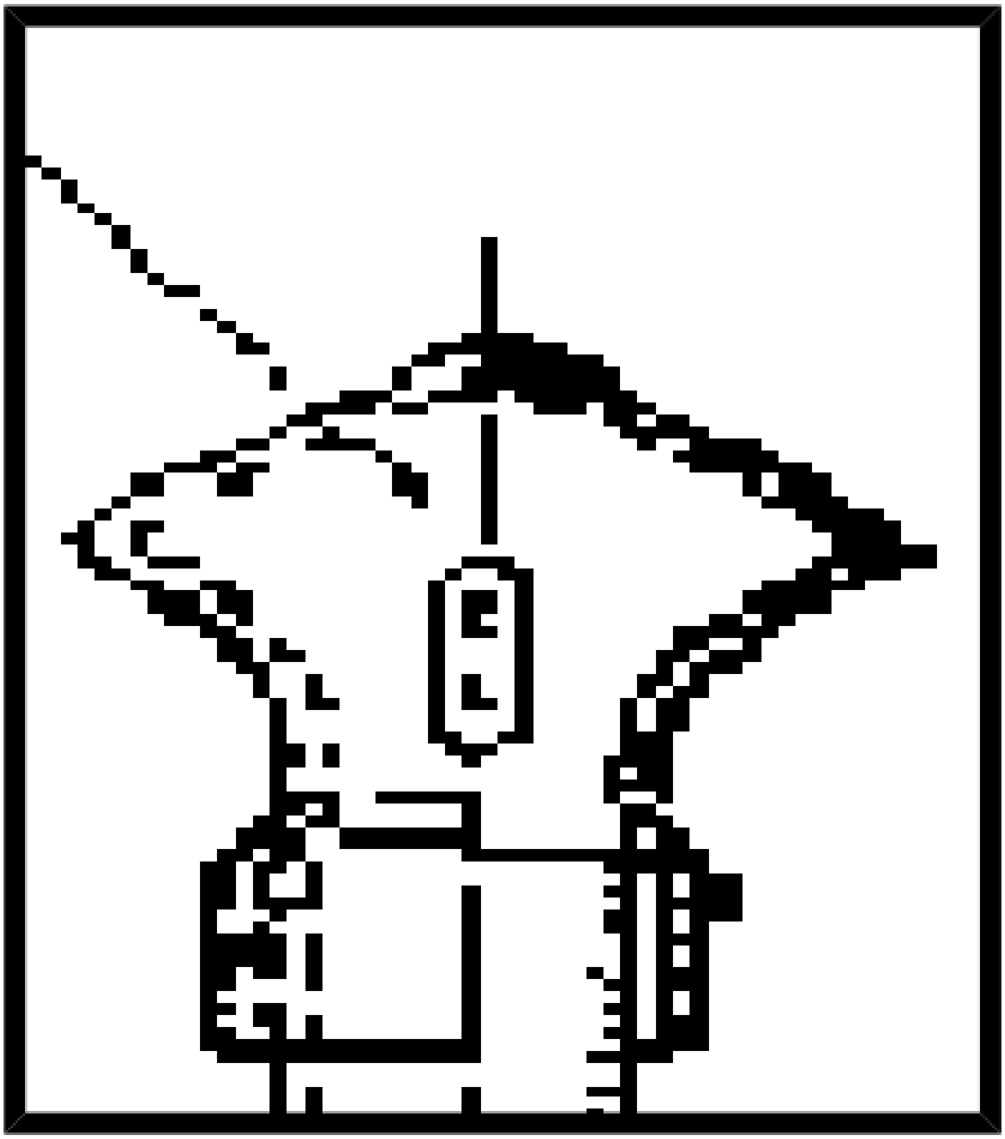
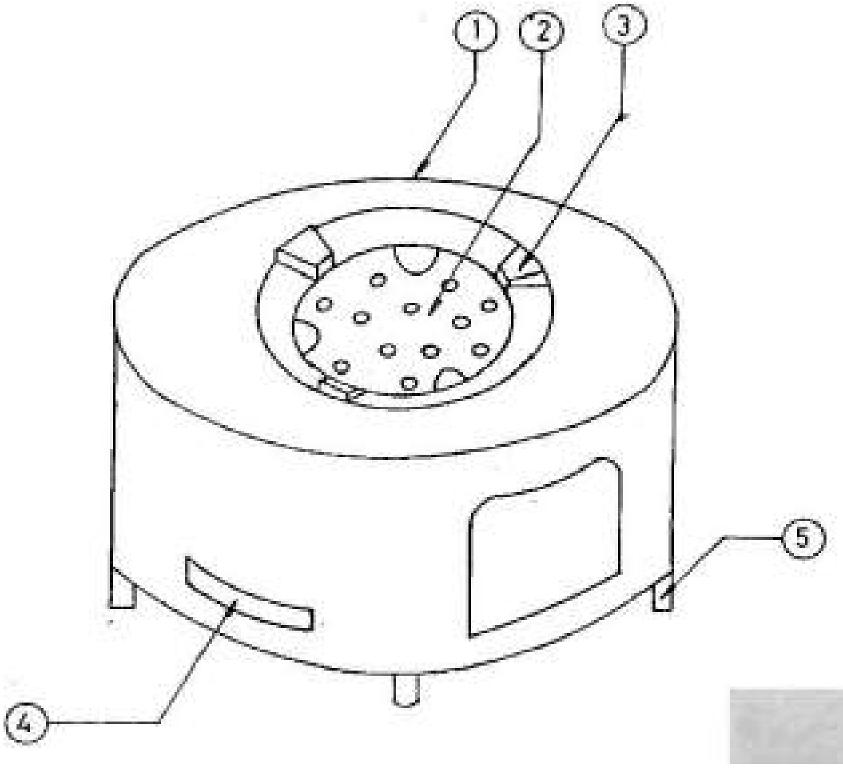


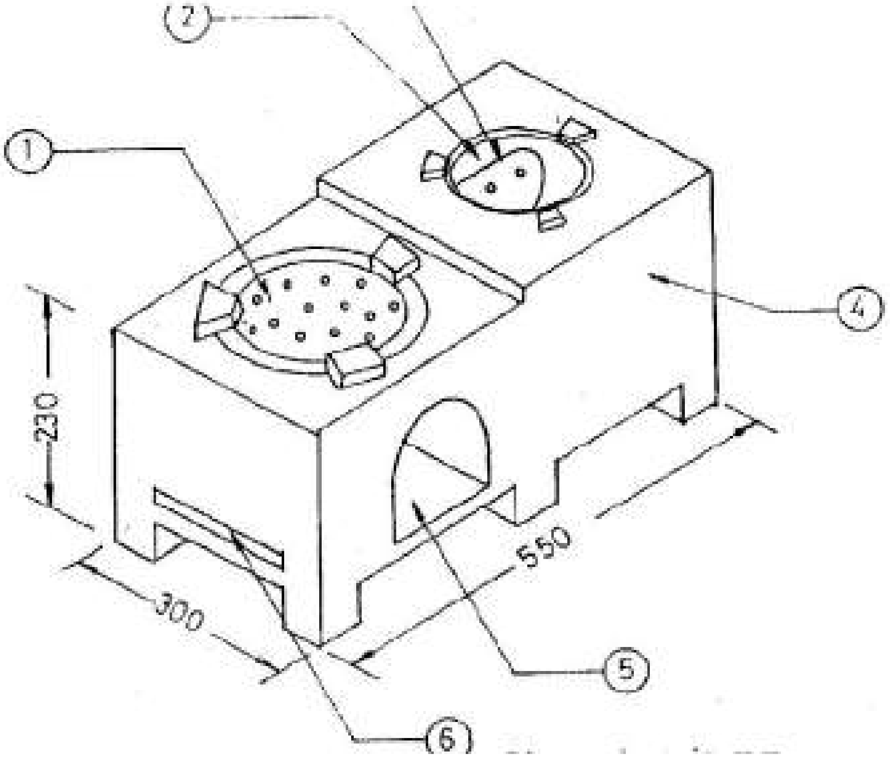
8) Tunnel

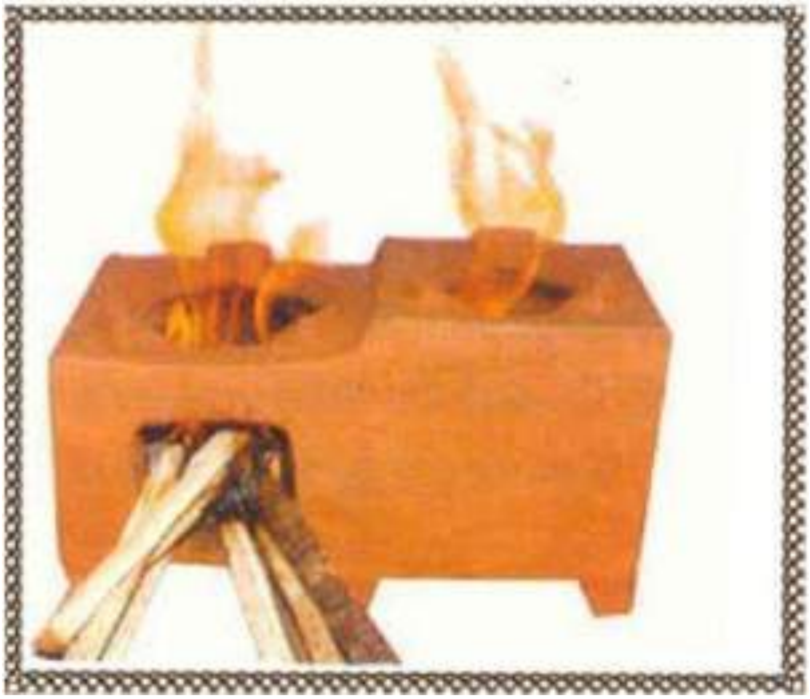
In multipot closed chulha the two or more pot holes are connected to each other by means of tunnels. Similarly the last pot hole and the chimney area also connected by means of a tunnel. The tunnel between the firebox and second pot hole should lead hot flue gases to the bottom of vessel placed on the second pot hole.

1.Outerwall 2.Innerwall 3.Mount 4.Airhole 5.Leg

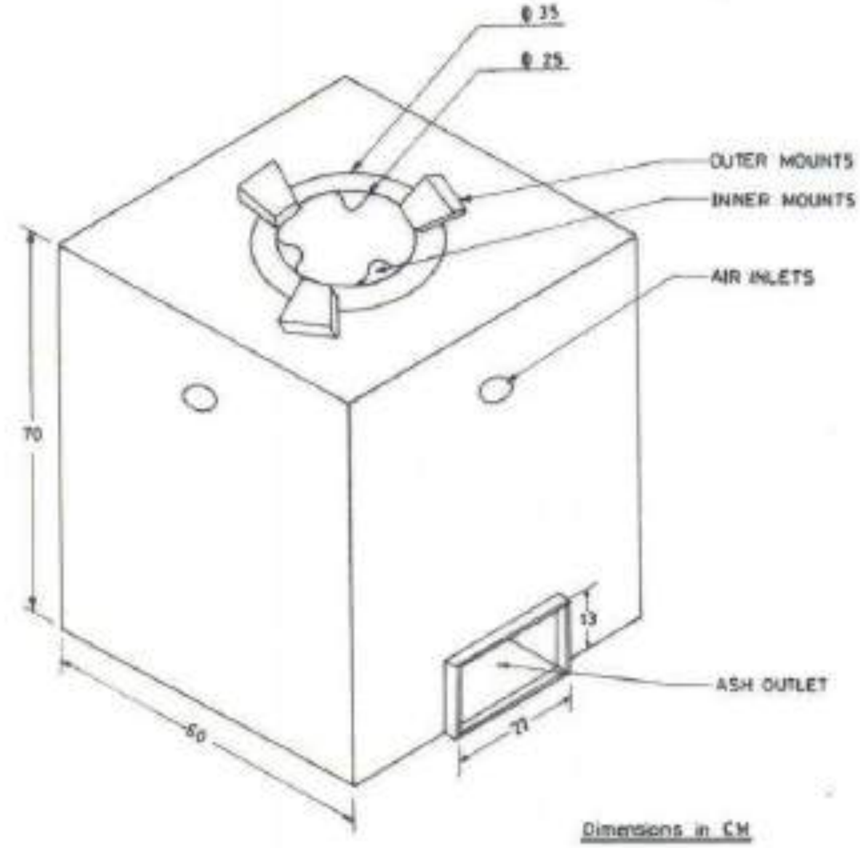


TNAU double pot chimneyless chulha

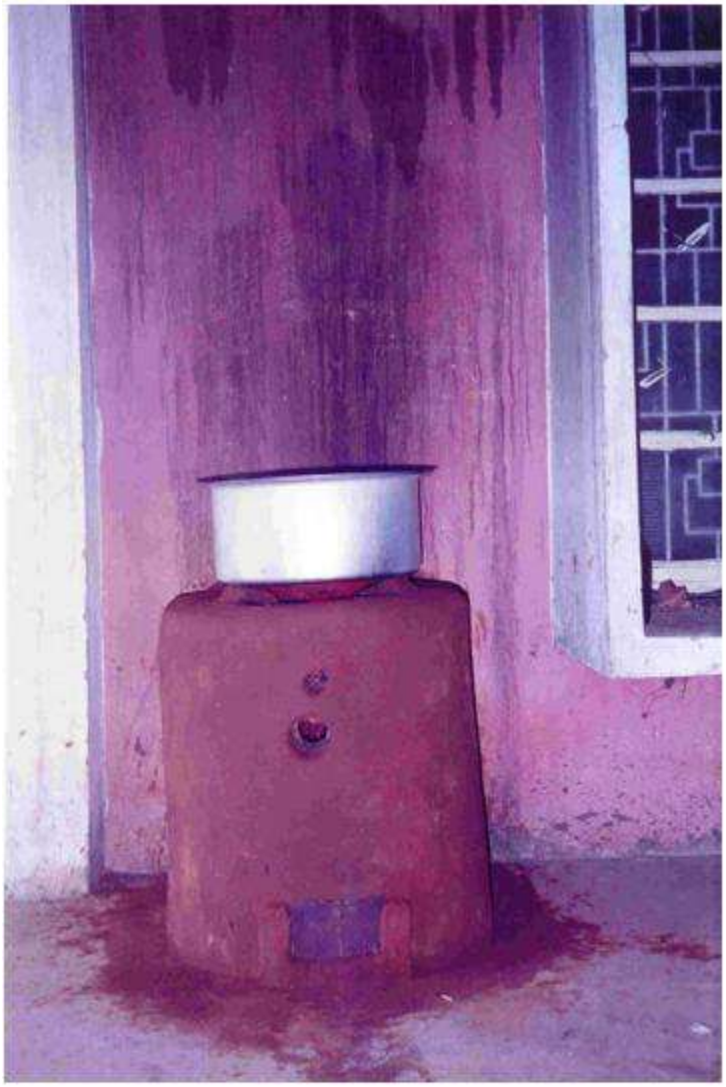




1.Firstpothole4.Outerwall
2. Second pot hole 5. Fire box 3. Tunnel 6. Air hole



Dimensions in CM



Improved chulla will have a efficiency of 20 – 25 %

Briquetting

Biomass briquetting is the process of converting low bulk density biomass into high density fuel briquettes with uniform size and shape for easy handling, transport, storage and uniform burning. Briquettes can be produced with the density of 1.2 to 1.4 g/cm^3 from loose agro residues with a bulk density of 0.1 to 0.2 g/cm^3. The process of briquetting consists of applying pressure to a mass of particles with or without a binder and converting it into a compact product of high bulk density, low moisture content, uniform size and shape and good burning characteristics.

India produces about 525 millions tonnes of crop and agro-processing residues annually. Presently about 100-125 million tonnes is not used properly and is available as surplus. Briquette replaces traditional fuel wood and kerosene both in domestic use and in small scale industries in developing countries.

Disadvantages of Raw Biomass

Relatively low heat value per unit volume.

Variability of quality and heat value.

Difficulty in controlling the rate of burning.

Rapid burning, necessitating frequent refueling.

Difficulty in mechanizing continuous feeding.

Large area requirement for storage.

Economic problems in transportation and distribution.

Several of these undesirable attributes result from the low mass and low volume energy density of biomass .

Need For Densification

In its natural form biomass is often an inefficient fuel because it is bulky, wet and dispersed. Among the options for conversion of biomass into energy intensive fuels, densification of biomass is a simple and economic proposition. Densification yields an economically viable solution to the storage volume, handling and transportation problems of different types of biomass. These briquettes have proved to be an improved and efficient fuel which burn as well as coal gives less smoke and leaves lose ash content. In bulk form, the density of the biomass is very low and hence cost of transportation and storage becomes very high and the efficiency of combustion is also low. So upgrading of biomass is essential to economically exploit its potential. Upgrading may involve one or more of size reduction, drying and densification.

Biomass Materials Suitable For Densification

The main raw materials comprising of forest and agricultural wastes are abundantly available in most parts of the country. The permissible moisture contents in the raw materials are 5-16%.The following are the types of waste products used for making briquetted fuel. The lingo-cellulose residues which includes Saw dust, sugar cane bagasse, cotton stalk, coffee husk, groundnut shell, wood, Wood shavings, Sunflower husk, Paddy straw, Rice husk, Wheat straw, Maize stalk, Cardboard waste, Corncob, palm fruit bunch, Tobacco waste, Mustard Stalk, Jute waste, Bamboo Dust, Tea waste, Soybeans husk, Other potential biomass residues suitable for briquetting are lentil stalks, lantana camara in hilly areas, tea wastes, and coir pith.

Requirement on Raw Material before Briquetting

Moisture content in the range of 10-15% is preferred because high moisture content will pose problems in grinding and more energy is required for drying. The ash content of biomass affects its slagging behavior together with the operating conditions and mineral composition of ash. Biomass feedstock having up to 4% of ash content is preferred for briquetting. Grain Size: powder or particles no more than 5×5mm is preferred. The granular homogeneous materials which can flow easily in conveyers, bunkers and storage silos are suitable for briquetting.

Raw Materials	K Cal / Kg
Bagasse	4200
Cotton salk	3800
Rice Husk	3500
Groundnut Shells	4000
Jute Waste	4500
Coffee Husk	4200

Briquetting Process

The series of steps involved in the briquetting process are
1.Collectionofrawmaterials
2.Preparationofrawmaterials
3.Compaction
4. Cooling and Storage.

Collection of raw materials

In general, any material that will burn, but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

Preparation of raw materials

The preparation of raw materials includes drying, size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

Drying

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), in solar driers, with a heater or with hot air.

Size reduction

The raw material is first reduced in size by shredding, chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1 to 10 mm).For some materials which are available in the size range of 1 to 10mm need not be size reduced. Since the size reduction process consumes a good deal of energy, this should be as short as possible.

Raw material mixing

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

Compaction

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.


Shredding machine

Briquetting Technologies

Briquetting technologies used in the briquetting of the agro residues are divided into three categories. They are

I. High pressure or high compaction technology (more than 100MPa).

II. Medium pressure technology (5 – 100 MPa).

III. Low pressure technology(Less than 5MPa).

High Pressure Technology

In high pressure briquetting machines, the pressure reaches the value of 100 MPa. This type is suitable for the residues of high lignin content. At this high pressure the temperature rises to about 200 - 250°C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material.

Medium Pressure Technology

In medium pressure type of machines, the pressure developed will be in the range of 5 MPa to 100MPa which results in lower heat generation. This type of machines requires additional heating to melt the lignin content of the agro residues which eliminates the use of an additional binder material.

Low Pressure Technology

The third type of machine called the low pressure machines works at a pressure less than 5 MPa and room temperature. This type of machines requires addition of binding materials. This type of machines is applicable for the carbonized materials due to the lack of the lignin material. The high pressure compaction technology for briquetting of agro residues can be differentiated in to two types

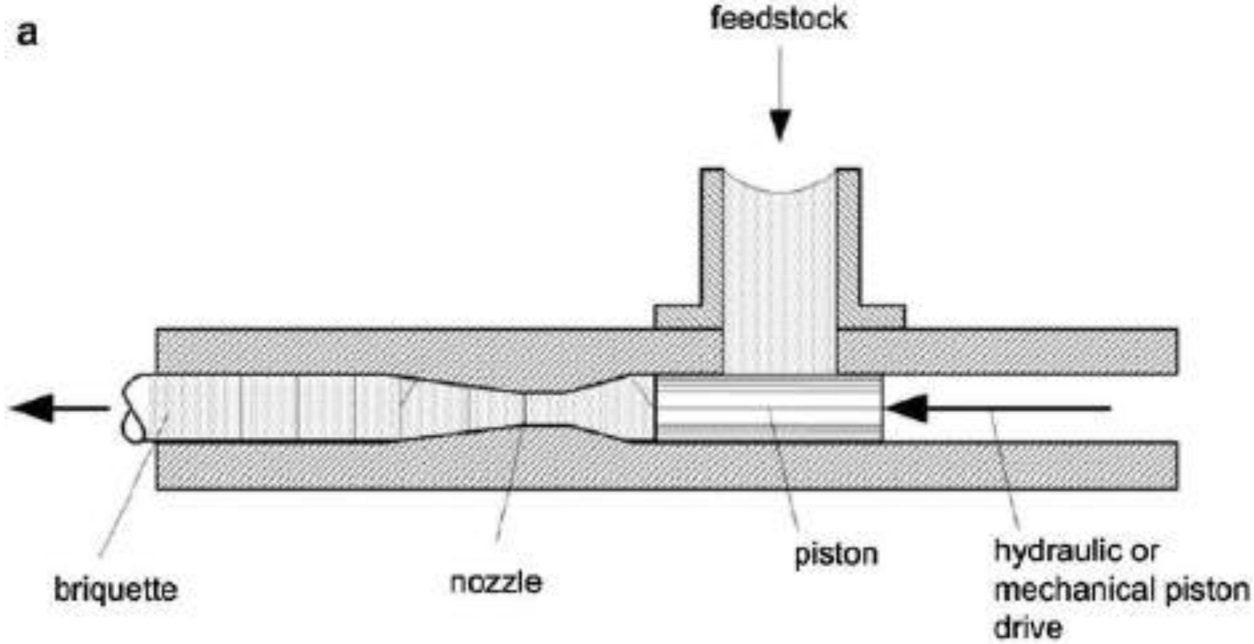
(i) Hydraulic piston press type and

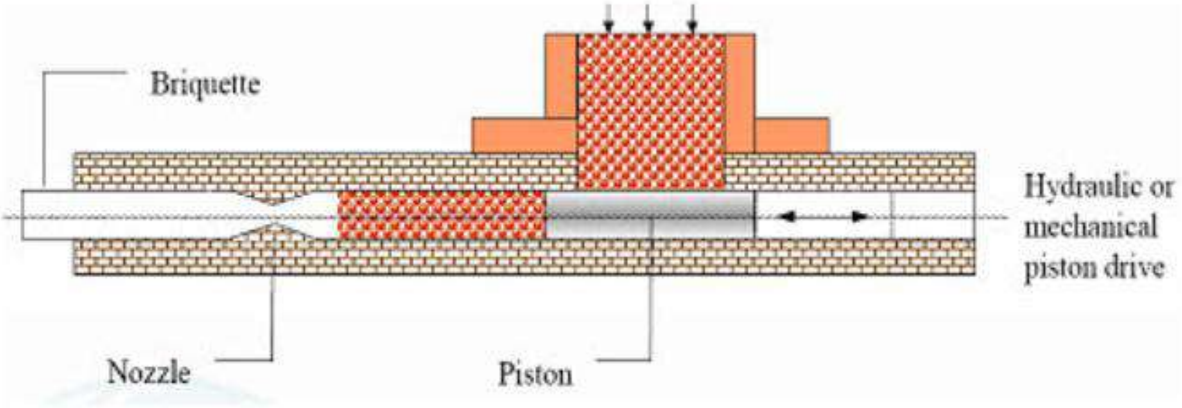
(ii) Screw press type.

Among these two technologies hydraulic piston press type was predominantly used to produce briquettes in India, particularly in TamilNadu all the briquette producing firms' uses hydraulic piston press technology for briquetting. Mostly cylindrical shaped briquettes with 30 mm to 90 mm diameter were produced. All the commercial firms involved in briquette making produces 60 mm and 90 mm diameter briquettes.

Piston Press

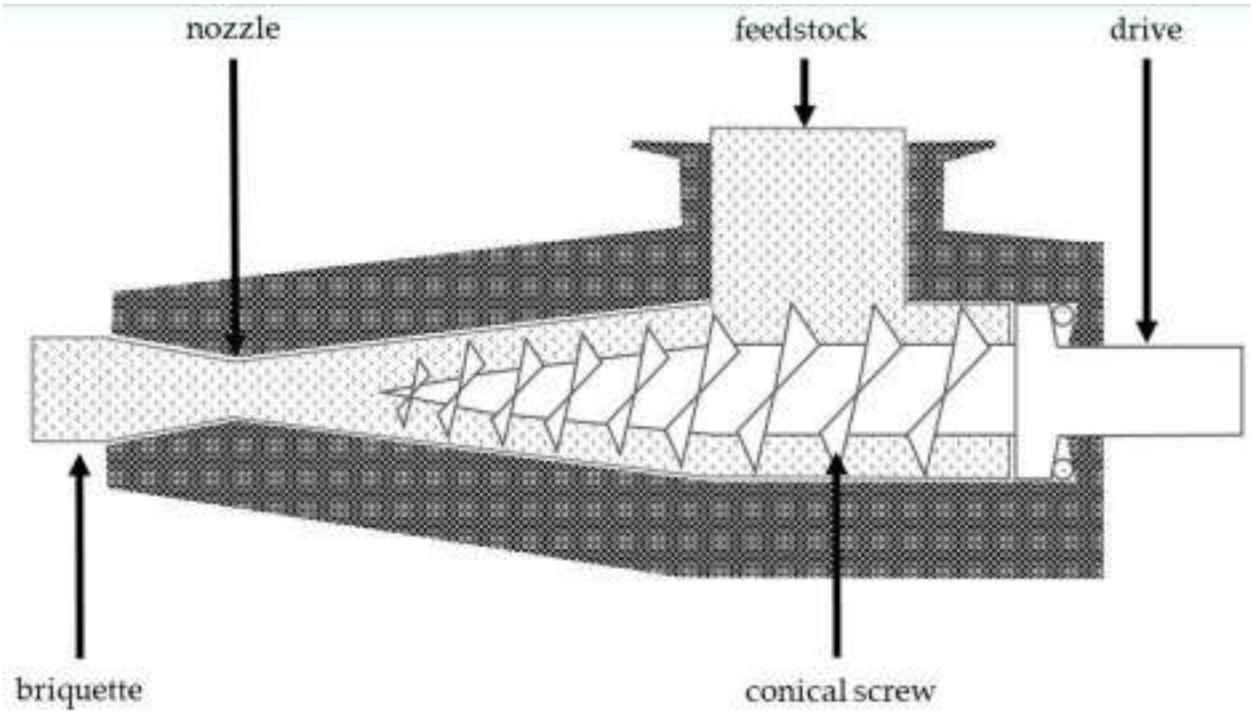
In the die and punch technology, which is also known as ram and die technology, biomass is punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product. The standard size of the briquette produced using this machine is 60 mm; diameter. The power required by a machine of capacity 700 kg/hr is 25 kW. The ram moves approximately 270 times per minute in this process.



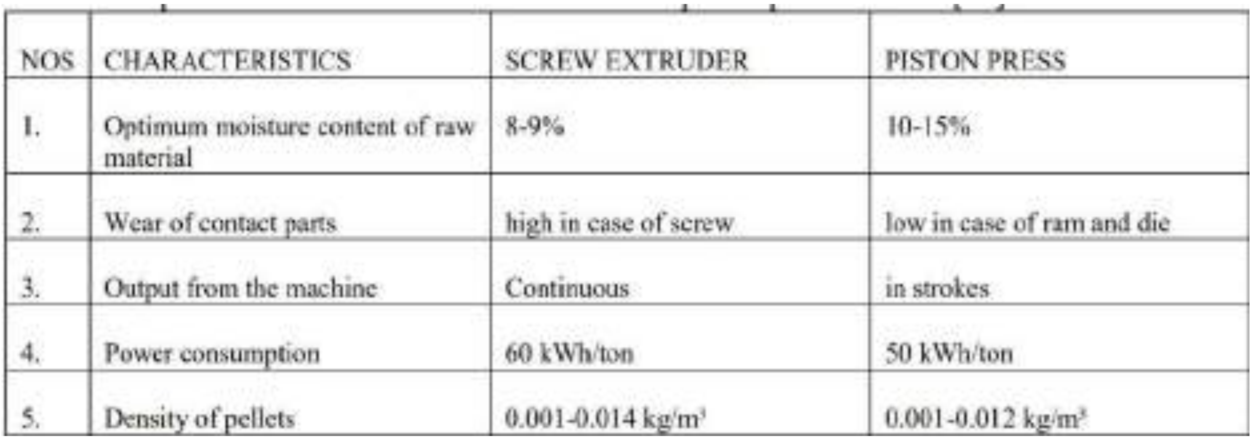


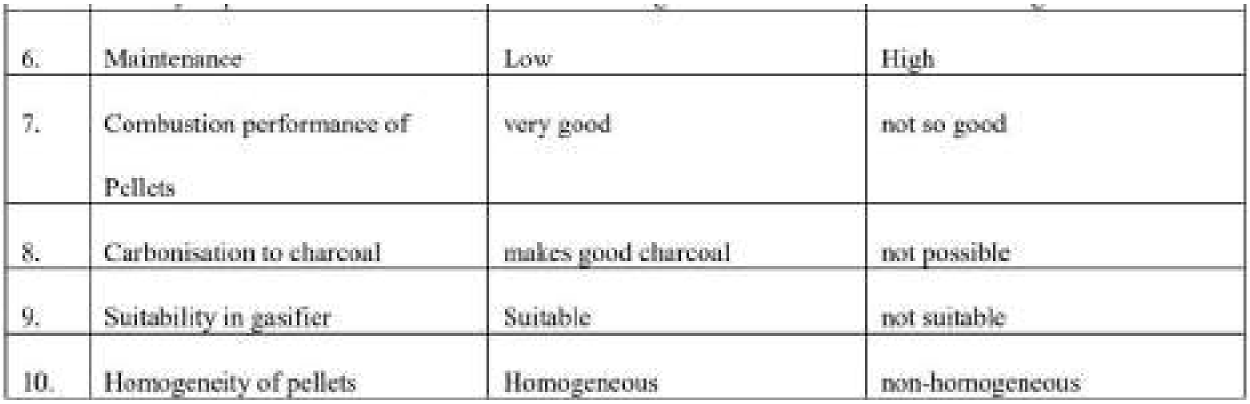
Screw Press

Screw Press In this process, the biomass is extruded continuously by one or more screws through a taper die which is heated externally to reduce the friction. Here also, due to the application of high pressures, the temperature rises fluidizing the lignin present in the biomass which acts as a binder. The outer surface of the briquettes obtained through this process is carbonized and has a hole in the centre which promotes better combustion. Standard size of the briquette is 60 mm diameter.



Comparison between a screw extruder and a piston press Source





NOS	CHARACTERISTICS	SCREW EXTRUDER	PISTON PRESS
1.	Optimum moisture content of raw material	8-9%	10-15%
2.	Wear of contact parts	high in case of screw	low in case of ram and die
3.	Output from the machine	Continuous	in strokes
4.	Power consumption	60 kWh/ton	50 kWh/ton
5.	Density of pellets	0.001-0.014 kg/m^3	0.001-0.012 kg/m^3
6.	Maintenance	Low	High
7.	Combustion performance of Pellets	very good	not so good
8.	Carbonisation to charcoal	makes good charcoal	not possible
9.	Suitability in gasifier	Suitable	not suitable
10.	Homogeneity of pellets	Homogeneous	non-homogeneous

Uses for Briquettes

The most frequent applications for this type of fuel are of both a domestic and industrial nature; from fireplaces or stoves to boilers generating hot water and steam. Tea industries, wine distilleries, textile industries, and farms are the major sectors using briquettes. Briquettes are also used in gasification process for electricity production.

]

Advantages of agro residual briquettes

The process increases the net calorific value of material per unit volume.

End product is easy to transport and store.

The fuel produced is uniform in size and quality.

Helps solve the problem of residue disposal.

Helps to reduce deforestation by providing a substitute for fuel wood.

The processes reduce/eliminates the possibility of spontaneous combustion waste.

The process reduces biodegradation of residues.

Biomass briquettes have a higher practical thermal value and much lower ash content (2-10% as compared to 20-40% in coal)

Energy Plantation

Energy plantations can be considered as long term alternatives to fossil and nuclear energy sources. When plants are grown purposely for their fuel value, by capturing solar radiation in, is called “Energy plantation. While there are significant quantities of agro waste, not all such waste can be used in specific equipments such as boilers. For some of the crop waste, their calorific value might not be high enough to make them attractive fuel choices. Collecting and transporting agro waste from multiple, distributed sources can pose significant logistics and supply chain challenges. For large scale users of biomass for energy generation, reliance on external sources for the main feedstock of their operations might not be optimal.

In recent years, to meet the demand of energy, plantation of energy plants has been re-emphasized. It is well known fact that trees have been intensively cut in Gangetic plains and coastal belts, leaving the area totally denude. India is the biggest fuel wood producing country in the world, but the per capita fuel wood production is very low *i.e.* 290 m^2/head. In view of getting maximum biomass, afforestation and forest management systems will have to be developed. These must include social forestry, silviculture (short-rotation forestry) tree-use systems, coppicing system, drought, salt-, pollutant - resistant plantations and high density energy plantations (HDEP). HDEP is the practice of planting trees at close spacing. This leads to rapid growth of trees due to struggle for survival. It provides quick and high returns, and opportunities for permanent income and employment.

Selection of Species

Therefore, annual plants should be grown to meet the demand of energy. Keeping in view the climatic and edaphic factors, plantation of deciduous trees should be encouraged, as their growth is faster than the coniferous ones.

The species to be planted should have the following characters:

i. Fast growth,

ii. Stress resistance,

iii. Less palatable to cattle and other animals,

iv. Early propagable,

v. High caloric value,

vi. Absence of deleterious volatiles when smokes come out,

vii. High yield of biomass, and

viii. Disease/pest resistant.

Social Forestry

Plantation through social forestry has been much emphasized by the Government of India to meet the demand of fuel and fodder in the rural areas. It will certainly decrease the gradually increasing pressure on the forests. This includes planting trees along road sides, canals, railway lines and waste lands in villages. Some of important plants are: Acacia nilotica, Albizia lebbek, A. procera, Anthocephalus chinensis, Azadirachta indica, Bauhinia variegata, Butea monosperma, Cassia fistula, Dalbergia sissoo, Eucalyptus globulus, E. citriodora, Ficus glomerata, Lagerstroemia speciosa, Madhuca indica, Morus alba, Populus ciliata, P. nigra, Terminalia arjuna, Toona ciliata, Salix alba and S. tetrasperma

Silviculture Energy Farms (Short Rotation Forestry

Silviculture energy farms employ techniques more similar to agriculture than forestry. The chief objective of energy plantation is to produce biomass from the selected trees and shrub species in the shortest possible time (generally 5-10 yrs) and at the minimal cost, so as to satisfy local energy needs in the decentralized manner. This would certainly relieve the pressure on the consumption of fossil fuel like kerosene and prevent the destruction of plant cover which is one of the primary components of the life support system (Khoshoo, 1988).

Advantages of Energy Plantation

Storage

Fuels produced by plant growth will have two main advantages over directly harnessing the solar energy at the surface of the earth either by thermal or photovoltaic means, i.e. neither of these two means can be counted upon for a continuous supply of energy unless it is equipped with elaborate storage units. Whereas plants, as they grow they serve as their own energy accumulator. There are practically no storage losses. This feature allows a considerable amount of flexibility in the reaping schedule for fuel crop. The flexibility is particularly wide if the crop maturity cycle extends over years. On the contrary similar flexibility is not available if crop matures in a few months. Perennial crops are always preferred for this purpose due to their continuous growth with minimum of efforts.

Economics

Economics of energy obtained through plantation will essentially depend upon (i) Cost of fuel mass produced in the comparison to conventional fuel. (ii) Cost of processing required, if any. Cost of fuel will depend on: (i) Cost of land used, i.e. in turn the yield of fuel per unit area/yr. (ii) Cost of plantation per unit area/yr.Cost due to land depends upon the duration of maturity cycle, 1.e. smaller maturity cycle means less cost. Cost due to land can be considerably reduced in having multiple crops and denser plantation, under optimized conditions the cost of energy obtained through plantation works out to be lesser than present fossil fuel cost on heat value basis as obtained by direct burning of wood.

Air Pollution

Most plant matter contains less than 0.1% sulfur and the problem of SO_2 pollution by the combustion of biomass practically non-existent.

Ash

Burnt matter leaves ash which is rich in nutrient-minerals unlike ash of fossil fuels. It can directly be used manure.

Ecological condition

Energy plantation will convert large tracks of semi-barren land into green belt and thus ecological conditions can be restored.

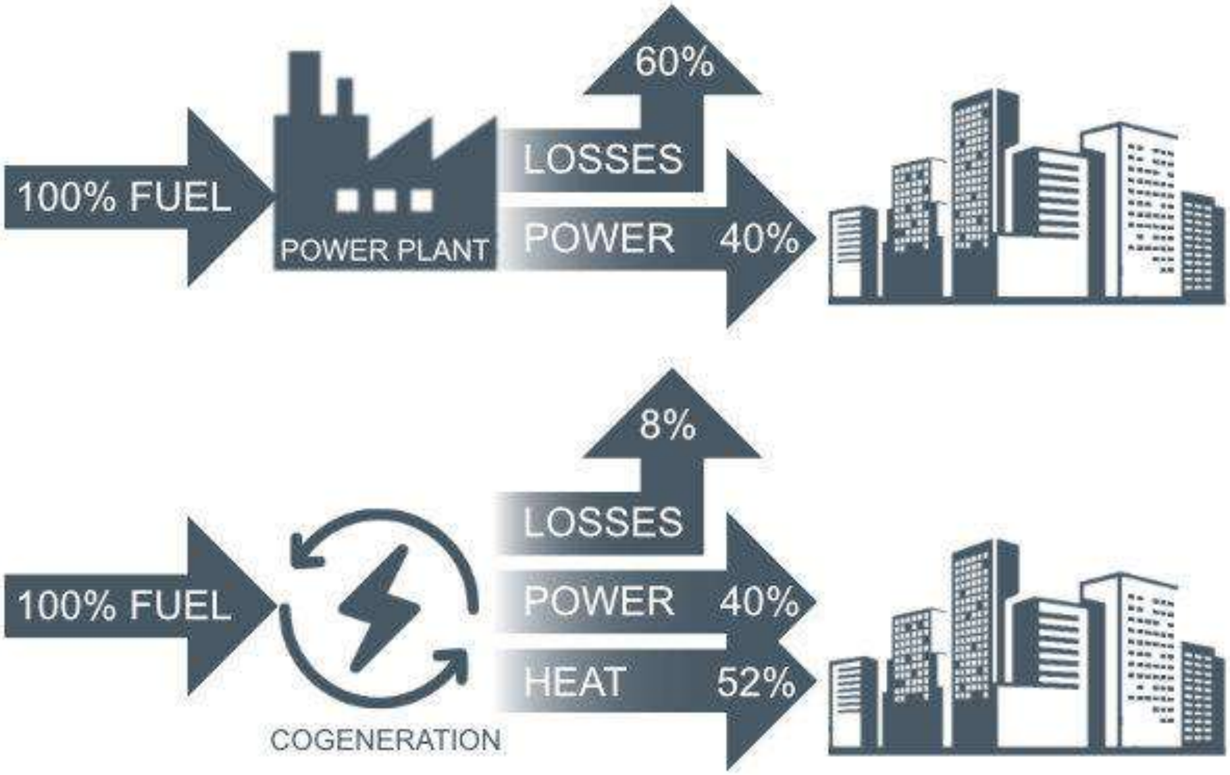
CO, balance of the Earth

Utilization of biomass for energy either by direct combustion or through production of liquid and gaseous fuels produces CO2. However CO2 thus produced does not disturb the CO2 balance in the atmosphere. Growth of biomass consumes Co2, as much as produced by consumption of biomass. Combustion of fossil fuel releases the CO2 in very large amounts and also they consume huge amounts of O2 from the atmosphere.

Cogeneration

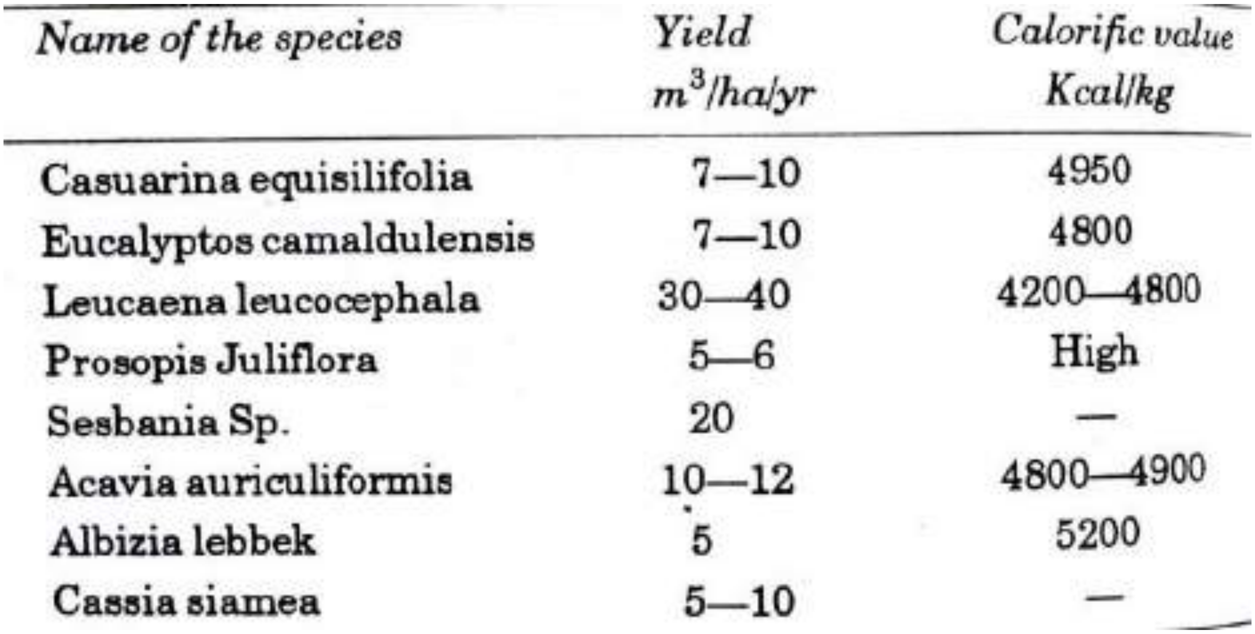
Cogeneration, also known as CHP or ‘Combined Heat & Power’, is an electricity generation method that works on capturing the losses typically suffered by traditional electricity generation processes. In its most basic form, it is the generation of both electricity and usable heat through an efficient ecological method of power production. The levels of fuel utilized in this kind of process sit at around 92%, meaning the losses incurred are considerably less than conventional energy generation (which is about 40 %!).

“Generation of Power & Heat from
a single fuel source”

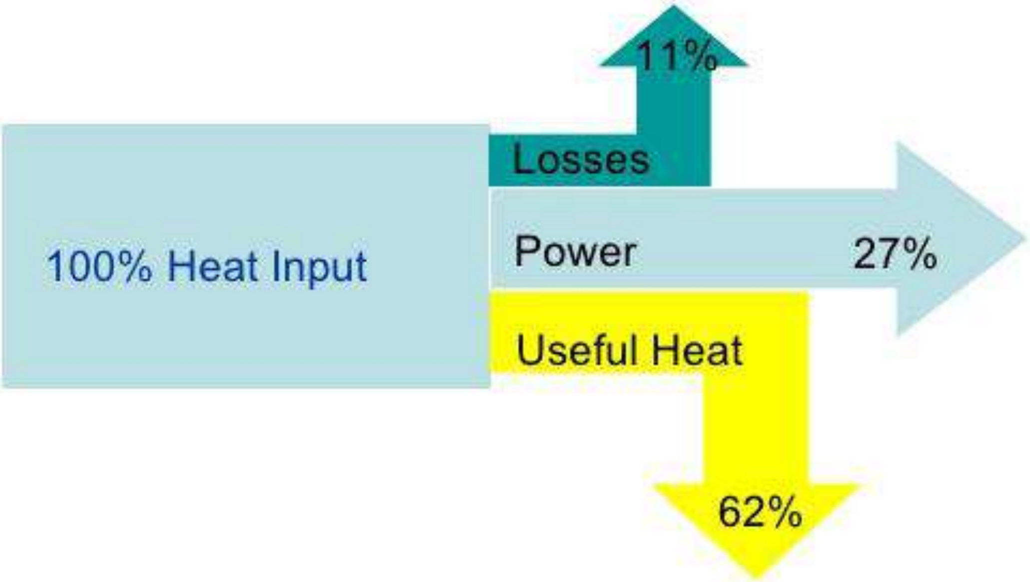


Cogeneration - Concept

Common Species Recommended



Name of the species	*Yield* m^3*/ha/yr*	*Calorific value Kcal/kg*
Casuarina equisilifolia	7—10	4950
Eucalyptos camaldulensis	7—10	4800
Leucaena leucocephala	30—40	4200—4800
Prosopis Juliflora	5—6	High
Sesbania Sp.	20	—
Acavia auriculiformis	10—12	4800—4900
Albizia lebbek	5	5200
Cassia siamea	5—10	—



Cogeneration – Concept

TYPES OF COGENERATION SYSTEMS

- This section includes various types of cogeneration systems:

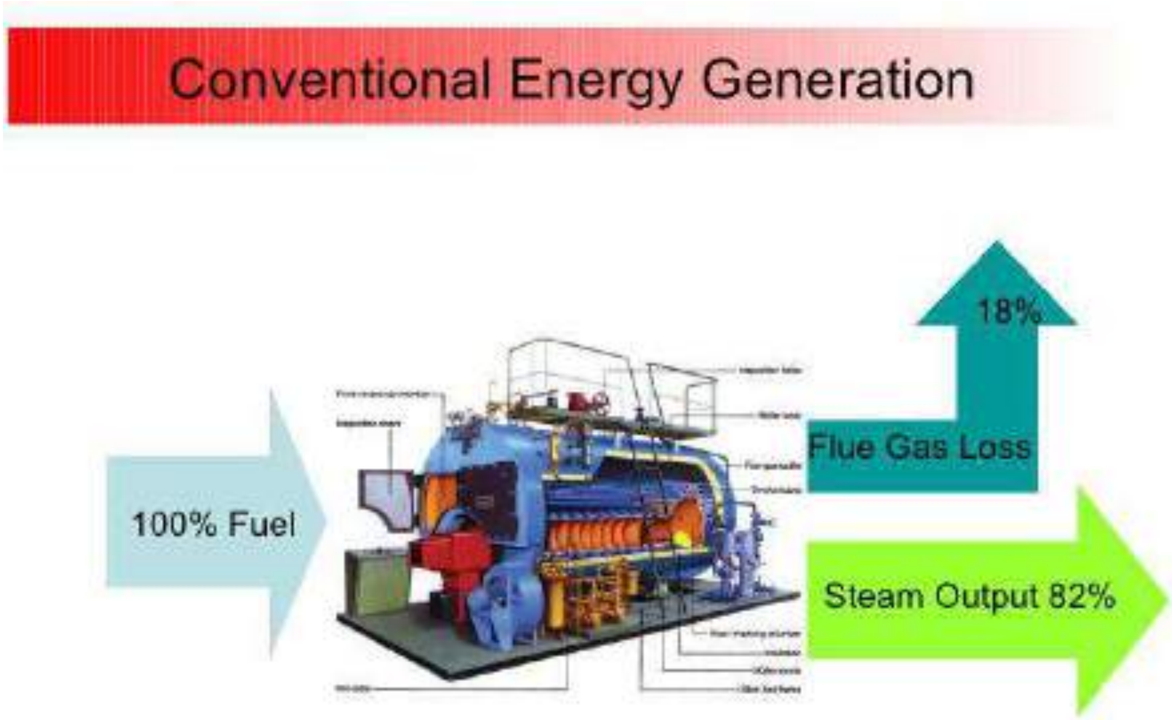
I. Steam turbine cogeneration system,

II. Gas turbine cogeneration system, and

III. Reciprocating engine cogeneration system.

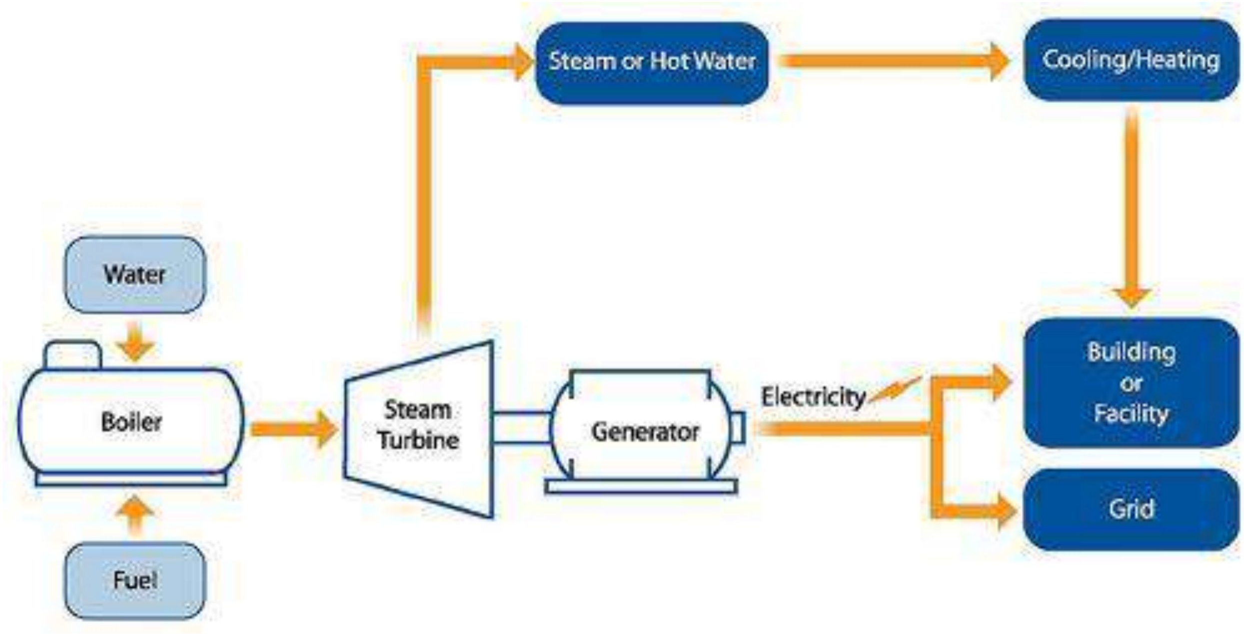
Steam Turbine Cogeneration

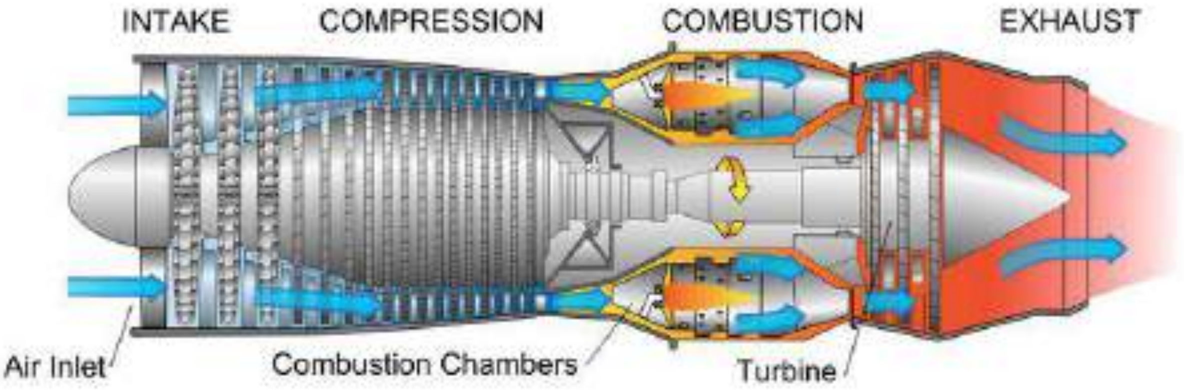
Steam turbines are widely used for combined heat and power (CHP) applications. The thermodynamic cycle for the steam turbine is the Rankine cycle. The cycle is the basis for conventional power generating stations and consists of a heat source (boiler) that converts water to high-pressure steam. In the steam cycle, water is first pumped to medium to high pressure. It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapor), and then most frequently superheated (heated to a temperature above that of boiling). A multistage turbine expands the pressurized steam to lower pressure and the steam is then exhausted either to a condenser at vacuum conditions or into an intermediate temperature steam distribution system that delivers the steam to the industrial or commercial application. The condensate from the condenser or from the steam utilization system returns to the feed water pump for continuation of the cycle.



Gas Turbine Cogeneration System

Most of the currently available gas turbine systems, in any sector of applications, operate on the open Brayton (also called Joule cycle when irreversibilities are ignored) cycle. Where a compressor takes in air from the atmosphere and derives it at increased pressure to the combustor. The air temperature is also increased due to compression. Older and smaller units operate at a pressure ratio in the range of 15:1, while the newer and larger units operate at pressure ratios approaching 30:1.





The Combustion take place when it mixed with fuel. The high pressure and temperature exhaust gases enter the gas turbine producing mechanical work to drive the compressor and the load (e.g. electric generator). The exhaust gases leave the turbine at a considerable temperature (450-600°C), which makes high-temperature heat recovery ideal.

Open – Cycle Gas Turbine Cogeneration

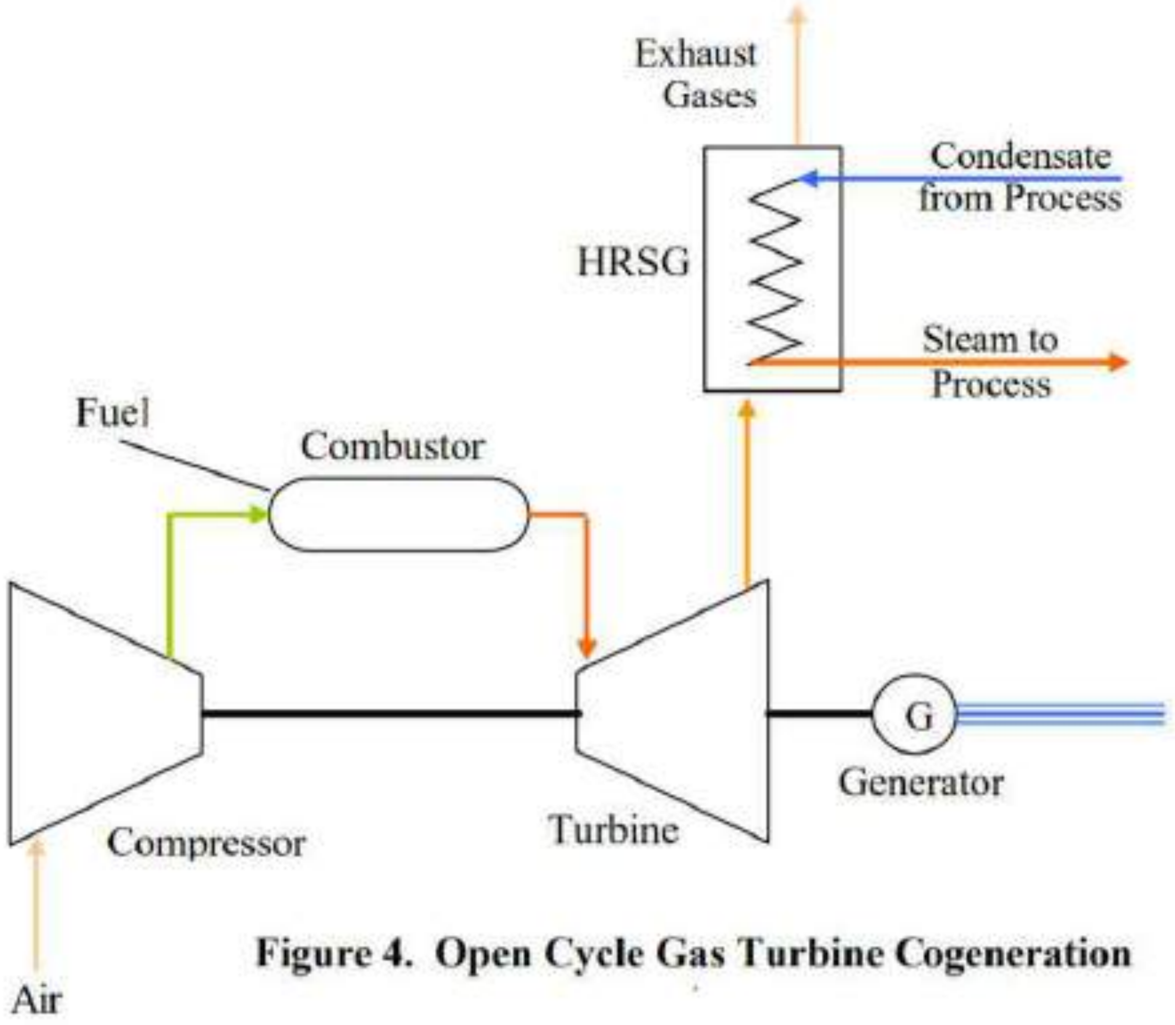
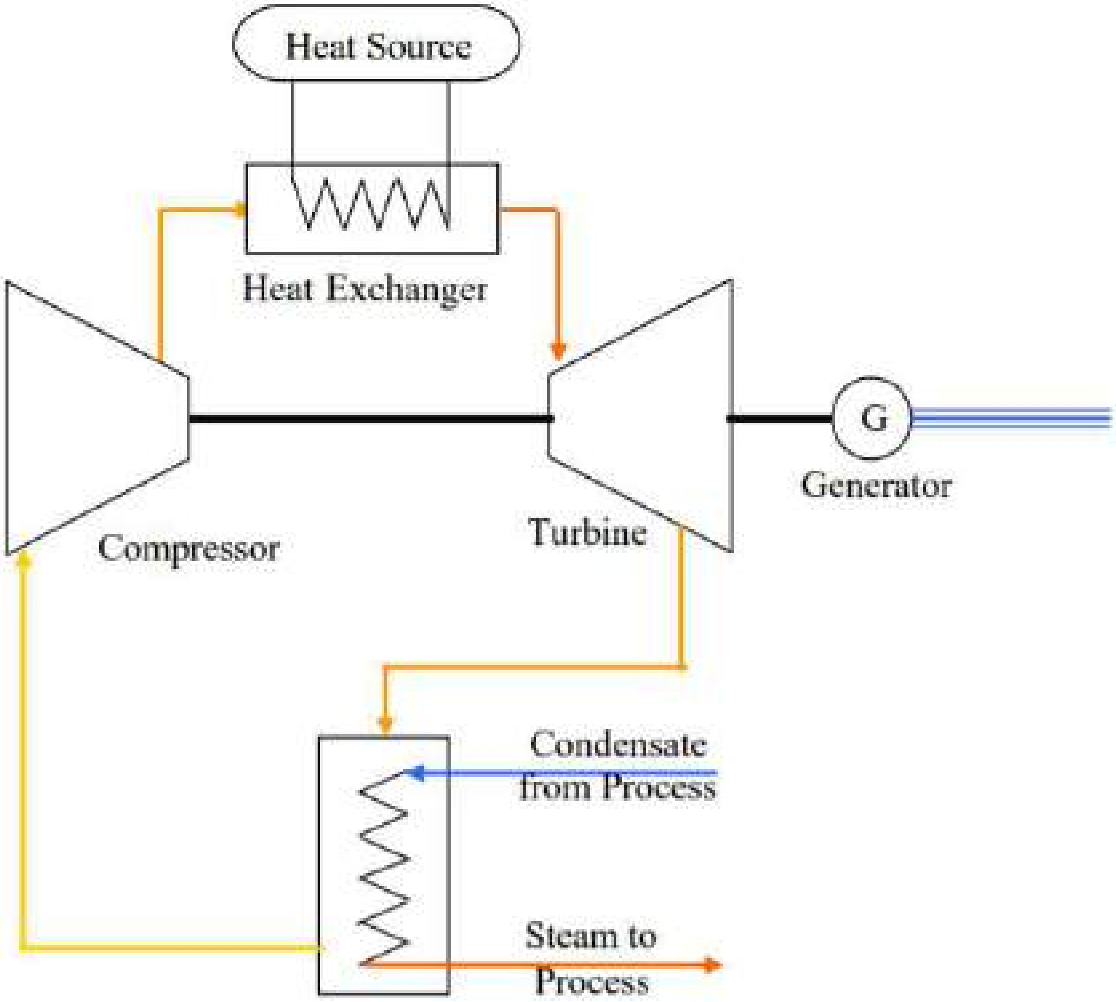
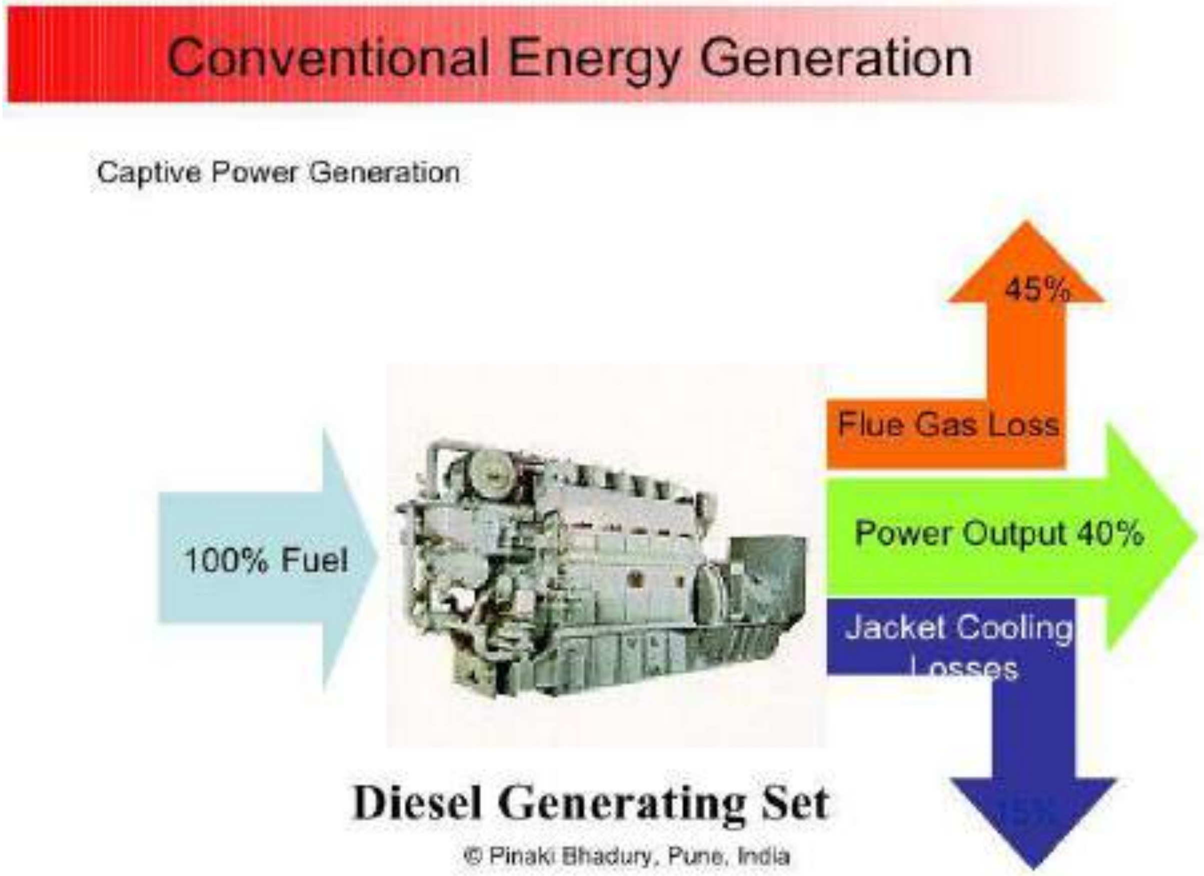


Figure 4. Open Cycle Gas Turbine Cogeneration



Reciprocating Engine Cogeneration System

Reciprocating engines are well suited to a variety of distributed generation applications, industrial, commercial, and institutional facilities for power generation and CHP.Reciprocating engines have higher electrical efficiencies than gas turbines of comparable size, and thus lower fuel-related operating costs.



Conventional Energy Generation

Captive Power Generation

100% Fuel

45%

Flue Gas Loss

Power Output 40%

Jacket Cooling Losses

15%

Diesel Generating Set

© Pinaki Bhadury, Pune, India

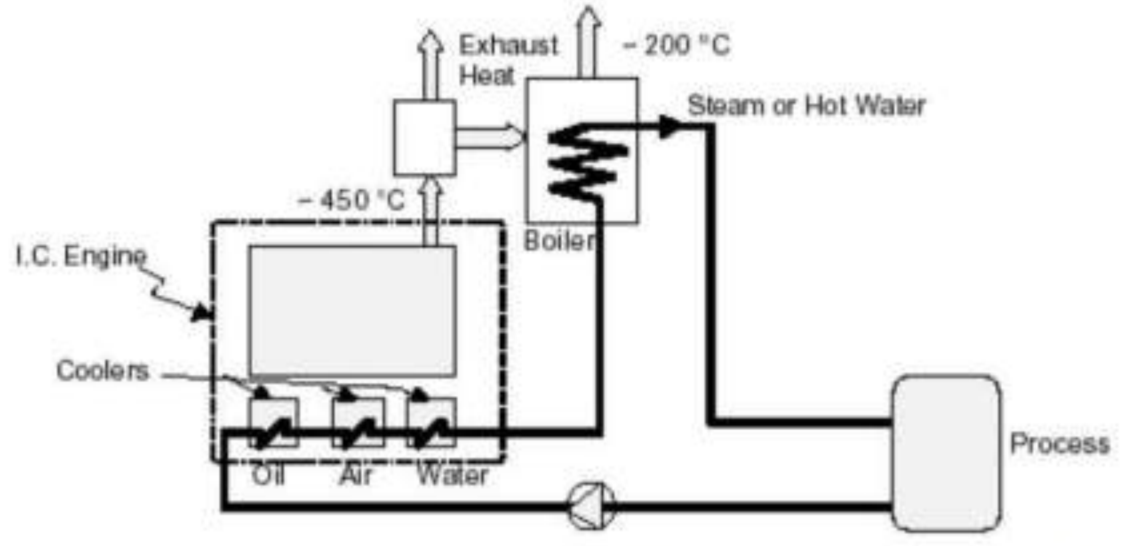


Figure 6: Reciprocating Engine Cogeneration System (UNESCAP, 2000)

TYPES OF COGENERATION SYSTEMS

It also includes a classification of cogeneration systems on the basis of the sequence of energy used.

I. Topping Cycle

II. Bottoming Cycle

Topping cycle

Topping cycle in a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.

Bottoming cycle

In a bottoming cycle, the primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants.

Benefits of Cogeneration

Increased efficiency of energy conversion and use .Lower emissions to the environment, in particular of CO_2, the main greenhouse gas. In some cases, biomass fuels and some waste materials such as refinery gases, process or agricultural waste (either anaerobic ally digested or gasified), are used. These substances which serve as fuels for cogeneration schemes, increases the cost effectiveness and reduces the need for waste disposal.

Large cost savings, providing additional competitiveness for industrial and commercial users while offering affordable heat for domestic users also. An opportunity to move towards more decentralized forms of electricity generation, where plants are designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier. An opportunity to increase the diversity of generation plant, and provide competition in generation. Cogeneration provides one of the most important vehicles for promoting liberalization in energy markets.

Bio-energy Policies

Most of the countries increased bioenergy use to attain the climate change targets of Paris agreement, 2015.India is one of the biggest consumers of petroleum products causing huge emission of CO_2. According to the International Energy Agency (IEA) India wouldbeamongthetopemission generating countries by 2030 and currently it ranked 3rd globally.

Most of the bio-power was obtained from bagasse-based combine heat and power (CHP) plants, to reach a total of over 4.4 GW by year's end. However, India's capacity additions were around 40% below those in 2012, and around 10% below the national target.Bioenergy has the potential to ensure energy security and improved energy access to remote parts of India. Theoretically, renewable biomass energy is a carbon neutral source of energy, which is used for the electricity and heat production. However, despite possessing such a climate friendly huge renewable power generation resource its utilization is still sub optimal.

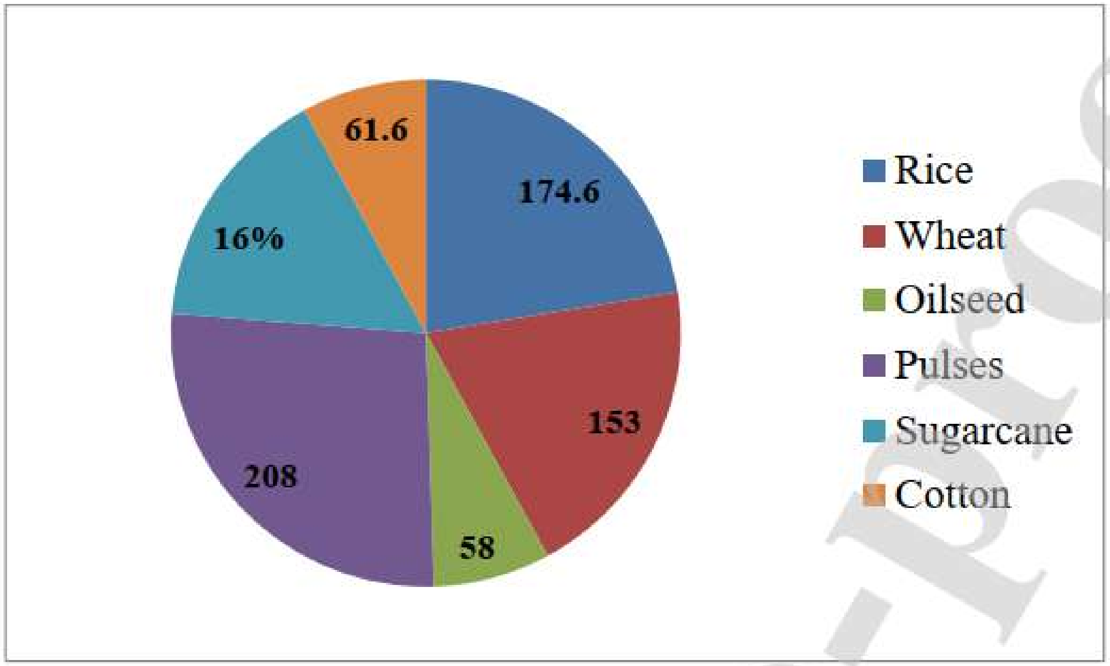


Fig.6. Major crops and residue generation (Mt/year) in India (2007-2012) [55].

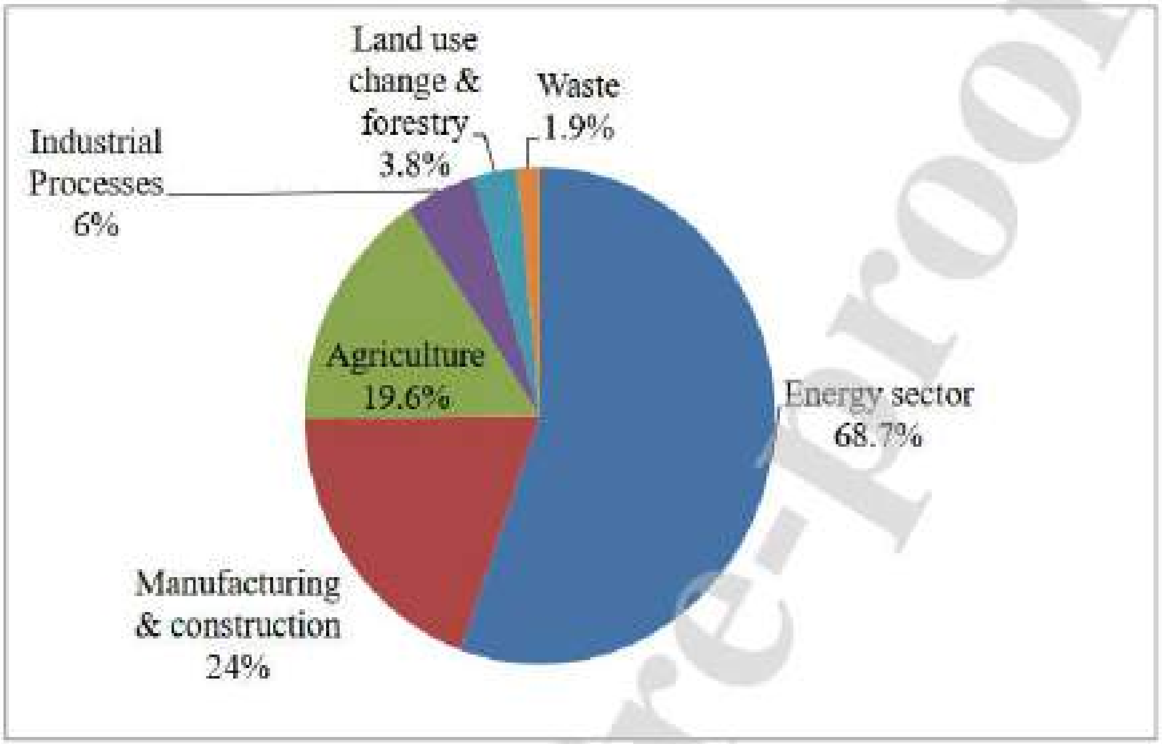


Fig. 2. Share of greenhouse gas emissions from different sources [4].

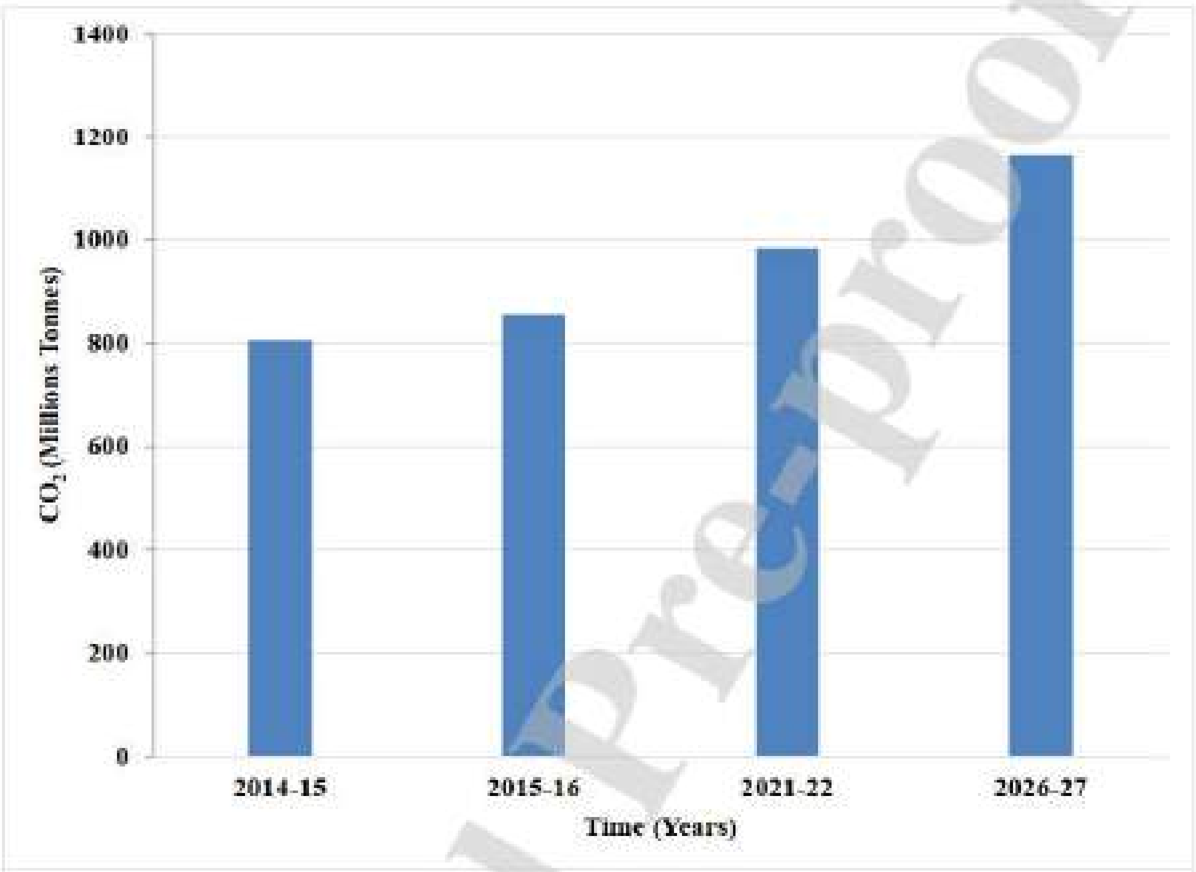


Fig. 1. Actual carbon emission from energy sector [3].

Currently, bioenergy policies of various countries adopting renewable and sustainable resources such as agriculture waste/residues, forest residues and municipal waste materials (MSW) instead of conventional resources because conventional bioenergy resources were based on human edible materials, which creates food scarcity problems. Therefore, these renewable bioenergy resources require policy framework for their optimum utilization.

Bioenergy Policies

Bioenergy policy introduced in the period of 1980s was mainly focused for improvement in efficiency of use of traditional biomass, biomass supply, and efficient use of biomass through technologies. These policies were dedicated to promote biomass based technologies and to established institutional framework to support and implementation of bioenergy programs.

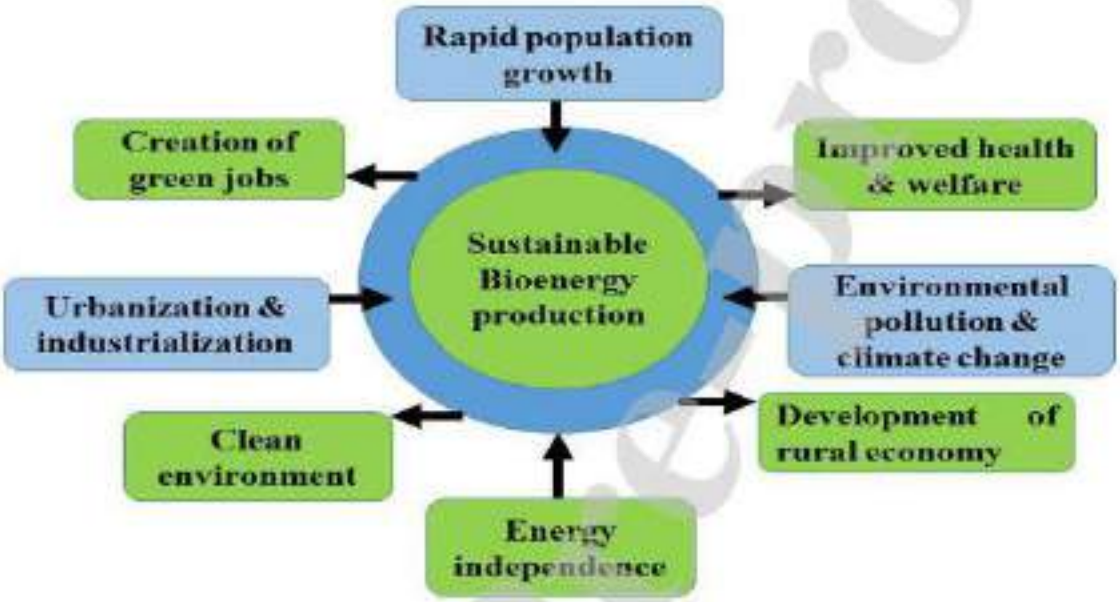


Fig. 3. Nexus for bioenergy development and their outputs.

History

The trigger for bioenergy development in India was oil crisis of 1970s.Initially, afuelpolicy committee (FPC) and a Working Group onEnergyPolicy(WGEP)weresetuptoprepareaconcretepolicy measures for non-conventional and available energy resource. Despite of having such committees for renewable energy development proper institutional frame work mechanisms were lacking. This institutional framework mechanism was first setup in 1980s, when Department of Science and Technology (DST) has created Commission on Additional Sources of Energy (CASE). This commission was restructured in to Department of Conventional Energy in 1982. An advisory board on energy was instituted in 1983, which proposed and recommended a Nodal Energy Conversation Organization (NECO). In 1987 Indian Renewable Energy Development Agency (IREDA) was notified as a "Public Financial Institution" under section 4 'A' of the Companies Act, 1956 and registered as Non-Banking Financial Company (NFBC) with Reserve Bank of India (RBI). IREDA works under the motto "Energy for Ever" with an objective to provide financial support to generate energy from renewable and clean sources

Programs to promote optimum and efficient use of biomass

Direct combustion and cogeneration programs were implemented to promote the optimum use of biomass resources for power generation. National program on improved 'Chulhas' (cooking stoves) was launched in 1985-1986 to replace the traditional cooking stoves by efficient mud-based cooking stoves and portable metallic stoves with chimney .

Off grid biogas generation power program

This program was an integration of biogas as well as organic manure generation. The program also improved sanitation in villages by promoting toilet to methane type biogas plant. The program was initiated by Khadi and Village Industries Commission (KVIC) and NGOs.

Village energy security program

It was lunched under 10th five-year plan to provide total energy demand of villages including lighting and cooking power with the involvement of local community. Local available biomass was focused as a feedstock for energy generation with promotion of social forestry programs for meeting the future biomass demand.

Implementations of the bioenergy policies by Indian government

National Policy on Biofuels – 2018

New national biogas and organic manure program (NNBOMP)-2018

Program on energy from urban, industrial and agricultural waste/residues.

Contemporary analysis of biofuels polices.

Bioenergy development in States and Union Territories of India

National Policy on Biofuels – 2018

In the background of National Biofuel Policy 2009, India launched its National Policy on Biofuel-2018 .The policy plans to increase the usage of biofuels in the energy and transportation sectors in the next 10 years. The policy also aims to substitute the fossil fuels by utilizing, developing and promoting domestic feedstock for the biofuels productions. The policy goal is to enhance the availability of biofuels for meeting the blending targets (i.e. 20 % ethanol blending in petrol and 5 % biodiesel blending) by 2030. The policy has potential to develop novel opportunities in the biofuels production sector of the country. The policy focuses on second generation biofuels which are lignocellulosic feedstock materials having low CO2 emission and do not compete with food crops for land use. The policy illustrates the scope of ethanol production from sugarcane juice and sugar-containing materials like sugar beet, sweet sorghum.

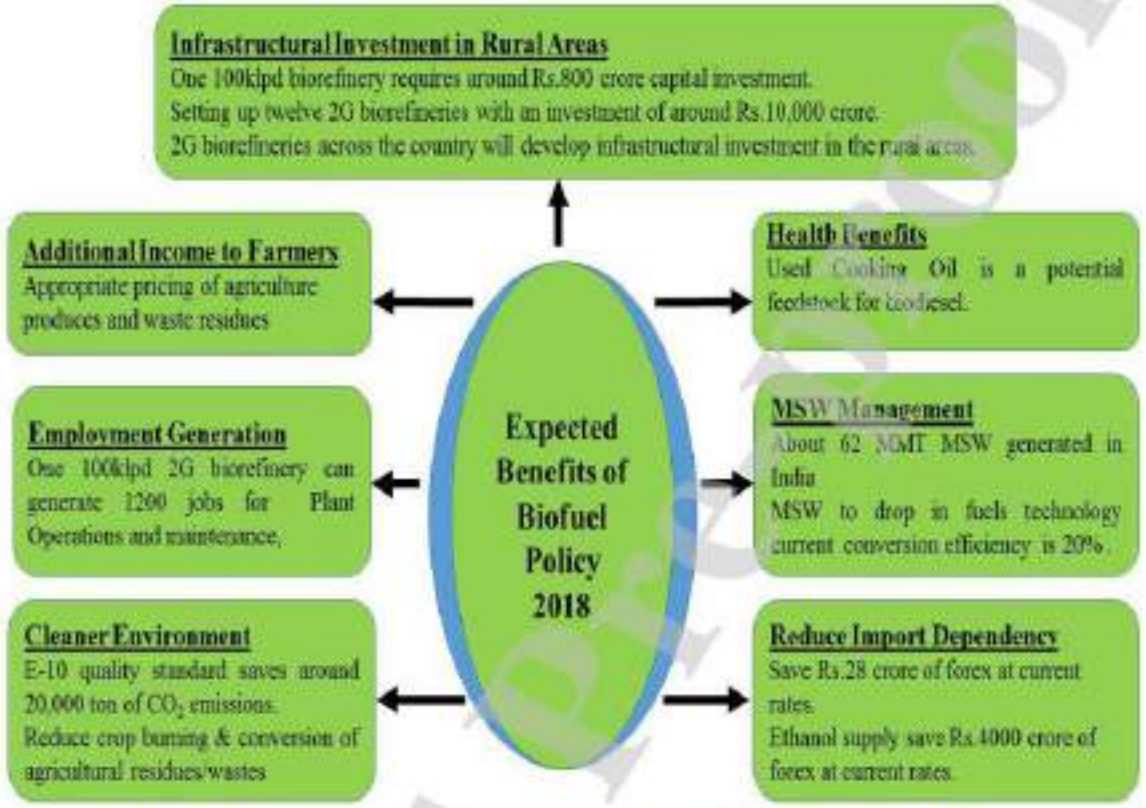


Fig.8. Expected Benefits of National Policy on Biofuels – 2018 [93].

New national biogas and organic manure program (NNBOMP)-2018

India has 512 million livestock population, which includes about 300 million total population of bovine, and the livestock sector contributes about 4% of GDP.NNBOMP is a multi-objective program of MNRE such as providing clean cooking fuel, fulfilling lighting, heating and other small power needs of rural and semi-rural households. In addition to these NNBOMP also seeks to improve organically enriched bio-manure production to lower the use of chemical fertilizers and reduction of GHGs emissions for a sustainable environment.

The target of NNBOMP is 2.55 lakh biogas plants having total biogas production capacity of 8.40 lakh m^3 per day by the end of 2019-20. MNRE provide subsidies on the biogas plants with capacity range from 1 m^3 to 25 m^3 per day in biogas production.

Program on energy from urban, industrial and agricultural waste/residues.

This program has a very broad scope including biogas and power production from industrial waste, sewage treatment plants, urban and agriculture wastes through biomethanation.It also focuses on installation of biomass gasifiers for captive power demands, promotional activities of research and development, resource assessment, performance evaluation and technology up gradation. The objectives of the program are energy recovery in the various form of biogas such as BioCNG from urban, industrial and agricultural wastes and to promote biomass gasifiers based power production for meeting the captive power and thermal requirements such as rice mills, village lighting, and water pumping.

Contemporary analysis of biofuels polices

National policy on biofuels-2009 was a well structured plan. Although, some of the targets have been achieved even then this policy has well defined preamble, vision, goal, definitions scope, and strategy and approval process. It has methodological illustration of various steps of intervention and enabling mechanism. Similarly, quality standards, international cooperation, import and export of biofuels, role of states, capacity building and synergies mechanism of institutions are elaborated.

Bioenergy development in States and Union Territories of India

Bioenergy support systems at state government level is still in nascent stage as compared to solar and wind, however central and state governments are continuously promoting bioenergy by various kind of activities. Biomass portal of India is a good initiative of MNRE, GOI disseminating information about bioenergy resources, feedstock materials, bioenergy technologies, bioenergy policies related to biofuels and relevant research articles. The portal does update the information regular intervals.

Broad Policy Recommendations

Integrating bioenergy policies with water, land, and agricultural policies—the success of bioenergy policies is impacted by site-specific conditions and policies for water, land, and agriculture (Souza et al. 2015a). Policymakers may generate more effective bioenergy policies when a policy is integrated with related policies, such as agricultural production and land-use, thereby helping to achieve multiple goals and alleviate some competition between food and energy for biomass and land (Souza et al. 2015a; UNCTAD 2014). This integrative approach may be supportive of more efficient and informed biomass production.

Integrating multiple energy sources and technologies in comprehensive policies—Bioenergy is a diverse arena that provides electricity, transportation, and heating from multiple sources of biological material and fuel types. Bioenergy also allows for flexibility by lending itself to the co-generation of end products within shared production facilities, such as both heat and electricity from biomass, as well as in combination with traditional fossil fuels, such as co-firing biomass with coal (Evans and Douraeva 2004; IEA-ETSAP 2015; REN21 2015). Policymakers may improve the effectiveness of energy policies by integrating multiple energy sources and technologies (IEA-ETSAP 2015; REN21 2015), while considering their appropriateness (Foust et al. 2015).

Assisting developing countries—Developing countries can face a number of challenges in developing and applying new technologies and policies, including infrastructure development (Pacini and Badtidzirai 2011; Pacini et al. 2014) and dissemination of knowledge (Souza et al. 2015a). Because developing countries may bear higher costs in implementing standards and may have different socio-economic challenges than developed countries (Souza et al. 2015a; Zarrilli 2008; UNCTAD 2014), policies can be improved by incorporating input from developing countries, such as in the development of sustainability standards and their implementation (Endres et al. 2015; Souza et al. 2015a; Zarrilli 2008). Furthermore, developing countries may benefit from policy analysis assistance (Pacini et al. 2014) and from