Waste and
By-product Utilization

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Module 1. Introduction to by-products and waste generation in agricultural production and processing

Lesson 1. By-products/waste, types of food by-product and waste, magnitude of by-products and waste in food production, magnitude of by-products and wastes in food processing

Availability of high quality, safe, nutritious food is fundamental need for good health and general well being of human being. Continuous supply of these foods has been major concern of civilizations all through the ages of human development. With rising urbanisation and limited natural resources like agricultural land, water and energy, producing good quality and nutritious food for all is a challenge. The food supply chain starts from field and end with consumer. It consists of different stages and stakeholders starting from farmers, intermediate handler/traders, processing industry, suppliers, transport, retailer, consumer and waste managers. All these players in the supply chain needs to devise ways and means for full utilisation of agricultural produce keeping the wastage (losses) to the minimum. The food manufacturing industry needs to transform agricultural resources, in addition to producing food for humans, into different component such that each of it may be used like animal feed, fertilizers, cosmetics, pharmaceuticals, bio-plastics and bio-fuels.

What is by-product/waste?

Foods wastes are usually organic residues generated by the processing of raw agricultural materials into food and are made up of liquid (wastewater) and solids.

The wastewater results from the cleaning processes or in the form of excessive or polluted process water. Its dry material content is typically less than 5% by mass. It possibly also contains organic or inorganic cleaning agents or disinfectants.

Solid food wastes with an organic origin have remarkably high water content (mostly about 80% by mass). They are usually characterized by a constant quality and purity due to the forgone processes. The fact that these substances are removed from the production process as undesirable ingredients makes them wastes.

The term ''**by-product**,'' which is common in industry, points up that these are mostly concealed usable substances, often with a market value. So the wastes could be considered valuable by-products if there were appropriate technical means to produce products whose value exceeds the cost of reprocessing. Residues in this case cannot be regarded as wastes but become an additional resource to augment existing natural materials. Recycling, reprocessing and eventual utilization of food processing residues offer potential of returning these by-products to beneficial uses rather than their discharge to the environment which cause detrimental environmental effects.

Types of food by-product and wastes

Five system boundaries have been distinguished in the food supply chains (FSC) which are mainly responsible for generation of wastages.

i) Agricultural production: Wastage of agricultural resources due to environmental conditions, losses due to mechanical damage and/or spillage during harvest operation (e.g. threshing or fruit picking), curing/ pre-treatments, on-farm temporary storage and sorting of crops etc.

ii) Postharvest handling and storage: including losses due to spillage and degradation during handling, storage and transportation between farm and distribution.

iii) Processing: including losses due to spillage and degradation during industrial or domestic processing, e.g. juice production, canning and bread baking. Losses may occur when crops are sorted out if not suitable to process or during washing, peeling, slicing and boiling or during process interruptions and accidental spillage.

iv) Distribution: including losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.

v) Consumption: including losses and waste during consumption at the household level.

Magnitude of by-products/wastes in food production

The food grain production in India has increased from 52.0 million tonnes in 1951-52 to 234 million tonnes by 2005. More than half of the dry matter produced annually in cereals, legumes, roots and tuber crops is the inedible phytomers. From country's annual crop production figures, the calculated residue production from the major food crops that are grown on nearly 50% of the country's cultivable area comes to about 306.6 million tonnes which is nearly 58% of the annual aggregate crop harvest of the major food crops (Table 1.1)

Table 1.1: Annual harvest of major food crops and crop residue (1999-2000)

S.No	Crop	Crop Production (mt)	Crop residue Produced (mt)
1	Wheat	74.3	111.4
2	Rice	88.3	114.7
3	Maize	11.6	17.2
4	Total pulses	13.1	14.4
5	Total oil seeds	21.2	42.4
6	Sugarcane	325	6.5
7	Total	533.4	306.6

Source: The Tribune, Chandigarh - Agriculture Tribune 2002

Magnitude of by-products/wastes in food processing

The food processing industry provides vital linkages and synergies between industry and agriculture. Raw materials - grain, livestock, milk, fruit, vegetables etc. -are converted into foodstuffs through processing activities which may involve other inputs - energy, water,

packaging and so forth. However not all inputs consumed result in useful outputs, and the result is waste.
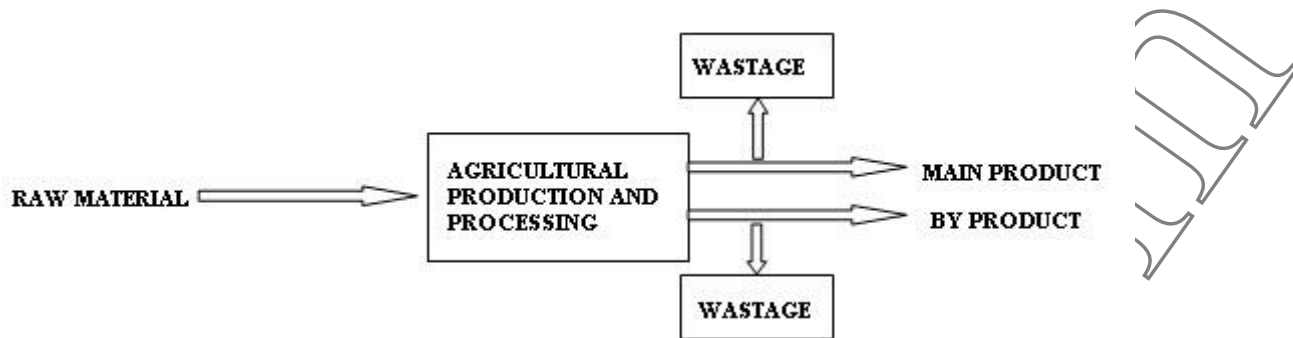
Food processing wastes are those end products of food industries that have not been recycled or used for other purposes. They are the non-product flows of raw/processed materials whose economic values are less than the cost of collection and recovery for reuse; and therefore discarded as wastes.

Typical wastes encountered in the food processing sector

- Food wastes – shavings, peelings, stones, animal by-products etc. in addition to wasted food

- Packaging waste - packaging of incoming materials and waste product packaging

- Waste water and liquid effluent

- General factory waste

Extent of food wastage

Roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally, which is about 1.3 billion ton per year. Food is wasted throughout the food supply chain (FSC), from initial agricultural production down to final household consumption. In developed countries food gets wasted at the consumption stage while in developing and low-income countries It is mostly lost during the harvesting and in post harvesting stages of the food supply chain (table 2). Little food is wasted at the consumer level.

Table 1.2: Comparison between by-products and waste

Parameter	By-product	Waste
Usability	Can be processed further or employed directly as final product	Not suitable for direct use. May be used after recycling or recovery
Intention of the holder	Transform it into useful product and market the material	Usually tends to discard the material
Certainty of use	Further use is certain	Often discharded
Legislation	Further use in compliance with all relevant product, environmental and health protection requirements for specific further use.	Waste management (i e recycling, recovery, disposal) as per waste disposal laws
Examples	Animal feed Fertiliser Cosmetics Pharmaceutical Bio-plastic Lubricant Bio-energy production	The following items if no longer used: Pallet Crates Plastic Paper Metal Wood

Table 1.3: Estimated/assumed waste percentage for each commodity group in each step of FSC for South and Southeast Asia (FAOSTAT 2010d)

Commodity	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereal	6%	7%	3.5%	2%	3%
Roots & Tubers	6%	19%	10%	11%	3%
Oilseeds & Pulses	7%	12%	8%	2%	1%
Fruits & vegetables	15%	9%	25%	10%	7%
Meat	5.1%	0.3%	5%	7%	4%
Fish & Sea food	8.2%	6%	9%	15%	2%
Milk	3.5%	6%	2%	10%	1%

Food manufacturers are increasingly acting as bio-refineries, in which agricultural raw materials are separated into a long series of products, comprising not only food but also feed, fertilizers, cosmetics, bio-fuels and others. Full utilization of this raw material in the food sector increases resource-efficiency and productivity, reduces bio-degradable waste and supports the transition to a bio-based economy (use of renewable resources).

Table 3: Food processing operations and associated waste

Catagory	Operations	Wastes
Raw material Preparation	Cleaning, Sorting, Grading, Peeling	Cleaning water effluent (BOD or COD), peelings, hair, feathers, grit, blood, contaminated foodstuffs
Size Reduction	Chopping, cutting, slicing, dicing, Milling of Solid foods, pulping Emulsification and homogenization of liquids	Poor quality (too coarse / fine) product with loss of nutritional / sensory characteristics Dust Agglomerates. Waste off-cuts. Fat bearing effluents from colloidal products (e.g. dairy) Risk of pathogenic contamination in emulsification (e.g. dairy)
Mixing and forming	Mixing, forming malformed pieces.	Wrongly proportioned batches, poorly mixed ingredients
Separation and Concentration	Centrifugation, Filtration Expression, Solvent extraction Membrane concentration	Separated solids (e.g. after clarification of liquids press residues (e.g. fruit juice extraction)
Fermentation and use of enzymes	Fermentation, Enzyme technology	Spent biomass.

Module 2. Waste management concepts

Lesson 2. Waste characteristics, waste management and effluent treatment

Waste is inevitably produced in all human activities; and its volume is proportional to the resources consumed. Waste is generally thought of as something that is no longer needed by the original user and is subsequently discarded. The increased culture of consumerism within our societies has escalated the problem of waste because of the use of disposable goods. Processed food wastes constitute one of the largest fractions of municipal waste these days. Manufacturing processes operate under strict quality control which has resulted in the generation of large volumes of food and packaging waste.

Transferring food from the field to the plate involves a sophisticated production and supply chain, but for the purposes of waste production this can be simplified into three main steps: agriculture, food processors/manufacturers and the retail / commercial sector. Each of the sectors generates waste and wash water. Given the complexity of the food chain, environmental impacts can occur at various points in the chain, even for a single food product. It is therefore necessary to take a holistic systems-based approach to tackle the problem.

Waste characteristics

The quality and quantity of wastes produced depend on the type of food being processed. There are big differences from sector to sector, and even site to site: generalization is not only difficult, but could also be misleading. Food wastages levels are often inferred from mass balances. It is estimated that about 21% of food product at the farm gate is lost, much due to spoilage, and only about 7%, on an average, is lost during processing. From the data cited in it can be inferred that, although the percentage loss during food processing is low, wastage mass or volumes are very high. The wastes produced in any food industry depend mainly on the type of food being processed. Food processing operations produce many varied types of wastes that can be categorized into solid, liquid and gaseous wastes.

Solid wastes

Solid wastes emanating from food processing plants may include: the unnecessary leftover from the preliminary processing operations, residues generated as an integral part of processing, wastes resulting from processing inefficiencies, sludge produced from the treatment of wastewater, containers for the raw materials and finished products. In general, solid wastes are poorly characterized, both in terms of quality and quantity; and estimates of solid wastes are usually inferred from mass balances.

Liquid wastes

Wastewater from the processing industry is the main stream that is produced. It includes: wastewater resulting from using water as a coolant, water produced by different processing operations like washing, trimming, blanching and pasteurizing and a large amount of wastewater produced from cleaning equipment.

Gaseous wastes

The gaseous emissions from the food processing industry are mainly manifested in terms of emanating odors and, to a lesser extent, in terms of dust pollution. Other emissions include solvent vapors commonly described as volatile organic emissions and gases discharged by combustion of fuels. Even though the characteristics of food wastes can be discussed in terms of their physical states, it is necessary to note that solid wastes contain a substantial proportion of water, just as liquid wastes may contain a significant proportion of solids. It is therefore absolutely critical to note that food wastes are not only multi-component but also multiphase in nature.

Waste management

Waste management is the collection, transport, processing or disposal as well as, managing and monitoring of waste materials. The term usually relates to materials produced by human activity, and the process is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is a distinct practice from resource recovery which focuses on delaying the rate of consumption of natural resources. All wastes materials, whether they are solid, liquid, gaseous or radioactive fall within the remit of waste management

Waste management concepts

There are a number of concepts about waste management which vary in their usage between countries or regions. The primary objective in waste management is to completely prevent the production of waste all together, if possible (Faulstich and Schenkel, 1994; EC, 1975). Second, if waste must be roduced, then it is to be recycled. Entirely avoiding waste production or recycling food waste in the food industry is extremely difficult. Some of the most general, widely used concepts include:

- The waste hierarchy refers to the "3 R s" **reduce, reuse** and **recycle**, which classify waste management strategies according to their desirability in terms of waste minimization. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The Rs are categories at the top of our disposal options. They include a variety of initiatives for disposing of discards. Generally, options lowest on the list are least desirable. However in Europe the waste hierarchy has five steps: reduce, reuse, recycle, recovery, and disposal. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. Some waste management experts have recently incorporated an additional R: "Re-think", with the implied meaning that the present system may have fundamental flaws, and that a thoroughly effective system of waste management may need an entirely new way of looking at waste. The 3R's of reduce, reuse and recycle have been considered to be a base of environmental awareness and a way of promoting ecological balance through conscious behaviour and choices. It is generally accepted that these patterns of behaviour and consumer choices will lead to savings in materials and energy which will benefit the environment.
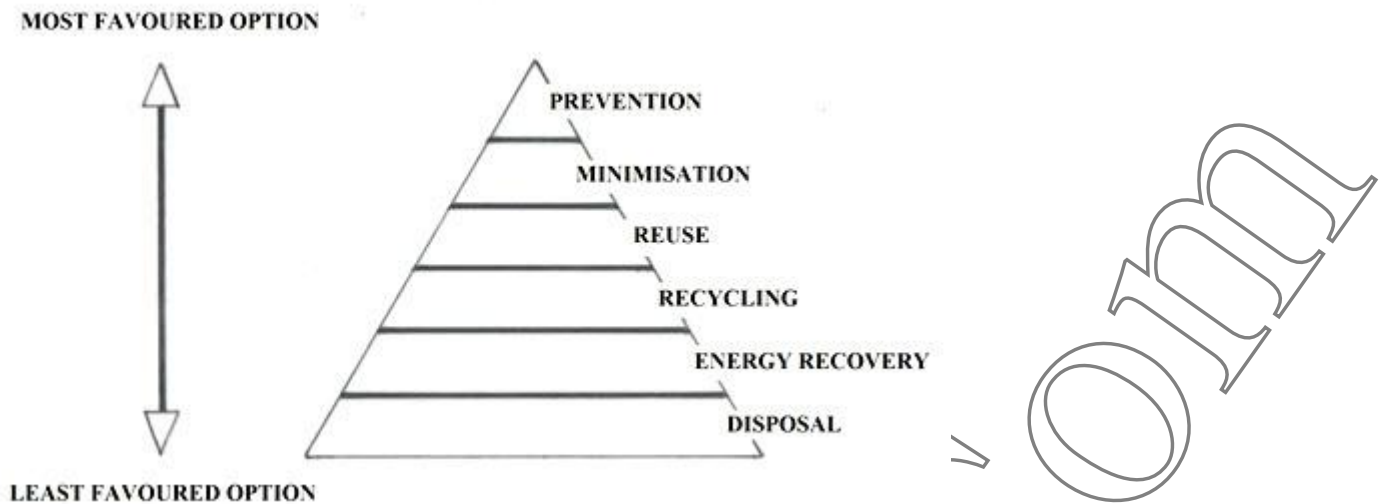
- Source reduction involves efforts to reduce hazardous waste and other materials by modifying industrial production. Source reduction methods involve changes in manufacturing technology, raw material inputs, and product formulation. At times, the term "pollution prevention" may refer to source reduction.
- Another method of source reduction is to increase incentives for recycling. Many communities in the United States are implementing variable-rate pricing for waste disposal (also known as Pay As You Throw - PAYT) which has been effective in reducing the size of the municipal waste stream.
- Source reduction is typically measured by efficiencies and cutbacks in waste. Toxics use reduction is a more controversial approach to source reduction that targets and measures reductions in the upstream use of toxic materials. Toxics use reduction emphasizes the more preventive aspects of source reduction but, due to its emphasis on toxic chemical inputs, has been opposed more vigorously by chemical manufacturers.

Reduce

To buy less and use less. Incorporates common sense ideas like turning off the lights, rain barrels, and taking shorter showers, but also plays a part in composting/grass cycling (transportation energy is reduced), low-flow toilets, and programmable thermostats. Includes the terms Re-think, Recycle, Carpool, Efficient, and Environmental Footprint.

Reuse

Elements of the discarded item are used again. Initiatives include waste exchange, hand-me-downs, garage sales, quilting, travel mugs, and composting (nutrients). Includes the terms laundry, repair, regift and up cycle.

Recycle

Discards are separated into materials that may be incorporated into new products. This is different from Reuse in that energy is used to change the physical properties of the material. Initiatives include Composting, Beverage Container Deposits and buying products with a high content of post-consumer material. Within recycling there is distinction between two types:

The rest of the hierarchy

The Rs are not the only disposal options:

Generate

Capturing useful material for waste to energy programs. Which includes methane collection, gasification, and digestion, and the term recover.

Incinerate

High temperature destruction of material. Differs from gasification in that oxygen is used; differs from burning in that high temperatures consume material efficiently and emissions are controlled.

Devastate

To discard into the natural environment, or to "trash" the planet. Includes Litter, Landfill, Burn Barrels, Unnecessary Vehicle Idling, and Dumping discards onto land or into water

Polluter pays principle

The Polluter Pays Principle is a principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the unrecoverable material.

The utilization and disposal of product specific waste is difficult for the following reasons (Werschnitzky et al., 1985; Russ et al., 1997; Russ and Meyer-Pittroff, 2004):

Biological stability and the potential growth of pathogens

Many types of waste material either already contain large numbers of microbes and/or will be altered quickly through microbial activity. If regulations concerning infectious disease are not properly observed, then hygienically unacceptable conditions can arise, e.g., through maggots or moulds. The breakdown of protein is always characterized by the generation of strong odours.

High water content

The water content of meat and vegetable waste lies between 70 and 95% by mass. High water content increases transport costs of the waste. Mechanically removing the water through use of a press can lead to further problems with waste water disposal, due to the high level of organic material in the water.

Rapid autoxidation

Waste with a high fat content is susceptible to oxidation, which leads to the release of foul-smelling fatty acids.

Changes due to enzymatic activity

In many types of waste arising from vegetables and fruits, enzymes are still active, which accelerate or intensify the reactions involved in spoilage.

Effluent treatment

Effluent is an out-flowing of water or gas from a natural body of water, or from a human-made structure. Effluent is defined as "wastewater - treated or untreated - that flows out of a

treatment plant, sewer, or industrial outfall. Generally refers *to* wastes discharged into surface waters". The Oxford English Dictionary defines effluent as "liquid waste or sewage discharged into a river or the sea". Effluent in the artificial sense is in general considered to be water pollution, such as the outflow from a sewage treatment facility or the wastewater discharge from industrial facilities

The nature of wastewater includes physical, chemical, and biological characteristics which depend on the water usage in the community, the industrial and commercial contributions, weather, and infiltration/inflow. It is 99.94 percent water by weight (Water Pollution Control Federation 1980). The remaining 0.06 percent is material dissolved or suspended in the water. The dissolved and suspended solids in wastewater contain organic and inorganic material. Organic matter may include carbohydrates, fats, oils, grease, surfactants, proteins, pesticides and agricultural chemicals, volatile organic compounds, and other toxic chemicals. Inorganic matter may cover heavy metals, nutrients (nitrogen and phosphorus), pH, alkalinity, chlorides, sulfur, and other inorganic pollutants. Gases such as carbon dioxide, nitrogen, oxygen, hydrogen sulfide, and methane may be present in wastewater (Lee and Lin, 2000). Wastewaters are normally treated by a combination of physical-chemical and biological operations. However, it is possible to treat waste waters solely with physical-chemical methods

Wastewater treatment is a series of steps. Each of the steps can be accomplished using one or more treatment processes or types of equipment. The major categories of treatment steps are:

1. Preliminary treatment

The purpose of preliminary treatment is to protect plant equipment by removing these materials that could cause clogs, jams, or excessive wear to plant machinery. In addition, the removal of various materials at the beginning of the treatment process saves valuable space within the treatment plant' Preliminary treatment may include many different processes. Each is designed to remove a specific type of material — a potential problem for the treatment process. Processes include: wastewater collections (influent pumping, screening, shredding, grit removal, flow measurement, pre-aeration, chemical addition, and flow equalization).

2. Primary treatment

The purpose of primary treatment (primary sedimentation or primary clarification) is to remove settle able organic and floatable solids. Normally, each primary clarification unit can be expected to remove 90 to 95% settle able solids, 40 to 60% TSS, and 25 to 35% BOD. Primary treatment reduces the velocity of the wastewater through a clarifier to approximately 1 to 2 ft/min, so that settling and floatation can take place. Slowing the flow enhances removal of suspended solids in wastewater. Primary settling tanks remove floated grease and scum, remove the settled sludge solids, Floating material (mostly grease and oil) is collected by a surface skimmer

3. Secondary treatment

Secondary treatment refers to those treatment processes that use biological processes to convert dissolved, suspended, and colloidal organic wastes to more stable solids that can either be removed by settling or discharged to the environment without causing harm. There are three commonly used approaches, and all take advantage of the ability of microorganisms to convert organic wastes (via biological treatment) into stabilized, low-energy compounds. The trickling filter (a bed of coarse media, usually rocks or plastic, covered with

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microorganisms) and the activated sludge process, sequentially follow normal primary treatment. The third, ponds (oxidation ponds or lagoons), can provide equivalent results without preliminary treatment.

4. Disinfection

Removes microorganisms to eliminate or reduce the possibility of disease when the flow is discharged. Like drinking water, liquid wastewater effluent is disinfected. Unlike drinking water, wastewater effluent is disinfected not to directly (direct end-of-pipe connection) protects a drinking water supply, but instead is treated to protect public health in general. This is particularly important when the secondary effluent is discharged into a body of water used for swimming or for a downstream water supply.

Module 3. Direct combustion of solid waste

Lesson 3. Proximate and ultimate analysis of biomass, theory of combustion, direct combustion of biomass as fuel in furnaces, operating conditions affecting design of furnace.

Biomass is a promising option for providing locally produced, renewable energy source. Biomass has been used as a fuel since millennia. Until the mid-19th century, biomass dominated the global energy consumption. With rapid increase in fossil fuel use, share of biomass in total energy has declined steadily over a century. Yet, biomass still contributes 14% of the world energy and 38% energy in developing countries (Woods and Hall, 1994). Globally, the energy content of biomass residues in agriculture industries annually is estimated at 56 exajoules (1 exajoule (EJ) is equal to one quintillion (10^{18}) joules), nearly a quarter of global primary energy use of 230 exajoules (WEC, 1994). Most biomass is not traded, but is homegrown or collected by the households. It is used very inefficiently and causes substantial health damages due to indoor air pollution. The improvements in biomass technology, environmental concerns like global climate change (Shukla, 1996), acid rain and the deterioration in local air quality from the use of fossil fuels have lately revived the interest in biomass energy as a renewable, sustainable and environmentally benign energy source. The rural energy crisis emanating from the low purchasing power of rural poor and the shortages of commercial fossil fuels have also contributed to the rising interest in the biomass energy. The cheapest biomass sources are the waste products from wood or agro-processing units. Their supply is however limited. In some industrialized nations, biomass has already penetrated under competitive dynamics. USA and Sweden obtain 4% and 13% of their energy respectively from biomass (Hall et al, 1992). Historically, biomass has been a major source of households' energy in India. Biomass meets the cooking energy needs of most rural households and half of the urban households (Shukla, 1996). Despite significant penetration of commercial energy in India during last few decades, biomass continues to dominate energy supply in rural and traditional sectors. Estimates of the share of biomass in total energy in India vary from nearly a third (36%) to a half (46%) of total energy (Ravindranath and Hall, 1995). Biomass energy constitutes wood fuels (including charcoal, wood waste wood), crop residues (such as bagasse, rice husk and crop stalks) and animal dung.

Biomass (solid waste) as fuel

Proximate analysis

It is a way of categorizing the organic composition of biomass. It is the breakdown of the fuel in volatiles, fixed carbon and ash. The proximate analysis is typically on dry basis. Most biomass will have a higher volatile content than coals. A general trend would be that the lower the lignin content, the higher the volatiles in the biomass. With waste biomass, depending on the fraction, the volatile content can be as high as 90 % of *dry and ash free (daf).*

 Proximate analysis of common biomass (% dry)

Biomass	Volatile Matter	Fixed Carbon	Ash
Paddy Straw	69.7	11.1	19.2
Wheat straw	71.3	19.8	8.9
Cotton stalks	72	24	4

Ultimate analysis

The elemental or ultimate analysis is the way to present the components in the organic part of fuels. It presents directly the main elements present in the organic part of biomass. The main elements of carbon, hydrogen and oxygen are indicated individually while secondary elements like nitrogen, sulphur, chlorine etc are all grouped together in "other" since they typically amount to much less than the three major elements.

Carbon (C) is obviously the most important constituent of biomass fuels. It mostly comes from the atmospheric CO_2 that became part of the plant matter during photosynthesis. It is the major contribution to the overall heating value and during combustion it is transformed back into CO_2, and released in the atmosphere.

Hydrogen (H) is another major constituent of biomass, as can be expected from the chemical structure of the carbohydrate and phenolic polymers. During combustion, hydrogen is converted to H_2O.

Nitrogen (N) is the most important nutrient for plants. It is absorbed via the soil or the applied N-fertilizers by the plant during its growth. In some waste fractions, the content of nitrogen may be quite high which contributes significantly to the degradability in biochemical processes like digestion or fermentation. During combustion and for all practical purposes, nitrogen does not oxidize in any significant quantities and is released in the gas phase as N_2 – therefore, its contribution to the overall heating value is zero.

Sulphur (S) is incorporated in several organic structures like amino-acids, proteins and enzymes. With waste fractions, where a mixture of organic substances forms the main part of the fuel, the content of sulphur may in some cases be significant. During combustion, sulphur is typically oxidized and has a minor contribution to the overall heating value. However, its most important impact relates to gaseous emissions syngas cleaning in gasification processes and corrosion issues

Chlorine (Cl)It is typically found in negligible amounts in coals and in wood (< 0.05 % on a dry basis), herbaceous biomass species have a chlorine content ranging from less than 0.1% to 2% or more. During combustion, chlorine is almost completely vaporized, forming HCl, Cl_2 and alkali chlorides. The problems associated with chlorine stem from issues related to emissions and operation issues, namely fouling and corrosion of metallic surfaces.

Oxygen (O) is a major element in all biomass fuels, as is evident from the nature of the photosynthetic process and the chemical composition of the biomass constituents. Fuel

oxygen reduces the amount of air needed for combustion and is found in the combustion products chemically bound in the molecules of CO_2 and H_2O.

Table 3.1: Ulimate analysis of selected dry biomass (%)

Element	Paddy straw	Wheat straw	Cotton Stalks	Wood	Bagasse
C	39.2	43.2	39.5	50	47
H	5.0	5.7	5.6	6.1	6.5
O	36.5	43.3	42.8	45	44
N	0.59	0.6	0.7	0.2	Ash 2.5
S	0.1	0.1			
Cl	0.3	0.3	0.5	<0.1	

The heat value (Calorific value) is the quantity of heat which is released by combustion of unit weight of fuel. It can be expressed in one of two ways: the higher heating value (Gross calorific value) or the lower heating value (net calorific value).

The higher heating value (GCV) is the total amount of heat energy liberated by the combustion of one kg of fuel taken at 0^0C under one atmosphere of pressure. The water present in the fuel as well as the water formed by combustion of the hydrogen being reduced to same condition.

The lower heating value (NCV) does not include the energy embodied in the water vapor i.e. water formed by combustion and the water of constitution of the fuel remains in vapour form. Generally, the GCV is the appropriate value to use   for biomass combustors, although some manufacturers may utilize the NCV instead.

For most agricultural residues, the heating values are in the range of 15 – 17 MJ/Kg

Theory of combustion

Burning is a chemical procedure through which a material rapidly reacts to the oxygen in the air producing intense heat and light; in the case of biomass burning, it involves three stages: ignition, flaming (burning and smoking with flame), smoldering (burning and smoking without flame). This burning is responsible for producing the main source of toxic gas, particulate matter and greenhouse-effect gases in the planet influencing the atmospheric physics and chemistry, producing rains with slightly changed the pH.

In practice the theoretical quantity of air is inadequate to mix with the entire quantity of fuel intimately. So air in excess of stoichiometric combustion is needed. By measuring CO_2 and

O_2 in the flue gases by Orsat apparatus, the excess air levels can be estimated. However, the excess air to be supplied depends upon type of fuel and the firing system.

Composition of atmospheric air

Oxygen = 23%, Nitrogen =77% (by mass)

Oxygen = 21%, Nitrogen = 79% (by volume)

Chemical Reactions:	Element Wt.	Molecular
$C + O_2 = CO_2$		
12 + 32 = 44 i.e. 12 kg of carbon requires 32kg of oxygen to form 44 kg of carbon dioxide or 1 kg of carbn dioxide therefore 32/12 = 2.67 kg of oxygen.	C	12
	O_2	32
$2H_2 + O_2 = 2H_2O$	H_2	2
4 + 32 = 36 i.e. 4 kg of hydrogen requires 32 kg of oxygen to form 36 kg of water. Therefore 1 kg of hydrogen requires 32/4=8 kg of oxygen.	S	32
	N_2	28
$S + O_2 = SO_2$	CO_2	44
	SO_2	64
32 + 32 = 64 i.e. 32 Kg of sulphur requires 32 kg of oxygen to form 64 kg of sulphur dioxide. Therefore 32/32kg= 1 kg of oxygen.	H_2O	18

Direct combustion of biomass as fuel in furnaces

There are four principal types of furnaces used to burn the biomass

- Step grate furnace
- Horseshoe furnace
- Ward furnace
- Spreader stoker furnace

Mostly step grate furnace is used.

Step grate furnace

Grate furnace combustion is a widely used conversion method to obtain heat and power from biomass. It is typically used for applications with a nominal thermal capacity of roughly 0.1−100MW. Grate furnaces can deal with a wide range of biomass fuel types (e.g. sawdust, wood pellets, bark, and fiber board) and are flexible regarding fuel size and moisture content. Grate furnace combustion is also applied to convert solid municipal waste.

The grate consists of small plates of cast iron arranged in steps. Its inclination to the horizontal should be 52^0. The grate consists of three parts:

1. The upper part or dead plate, without steps or opening for passage of air on which biomass is dried before passing on to the proper grate.

2. The grate proper corresponding to the steps. This helps to proportion the quantity of air passing through the biomass to the degree of combustion required.

3. The portion of slight slope or ash grate, at the lower end of the grate on which combustion of biomass is completed, leaving ash which falls into ash pit.

Advantages

- Different size of biomass can be burnt
- Biomass with high moisture content can be burnt.
- Low emission of fly ash

Disadvantage

- High emission of NO_2, CO etc.

Operating conditions affecting design of the furnace

All the furnace dimensions are fixed by the necessity to observe the following conditions:

i) Length of flame

The length of the passage for the burning gases, between the grate and boiler tubes, should be at least 5 m, and preferably 7-8 m. It should not exceed 10 m.

Below 7 m and particularly below 5 m, the gases would not be completely burnt on reaching the cold water, tubes, and the sudden cooling caused by their passage between the tubes would to a great extent arrest the combustion, thus increasing the proportion of CO, and decreasing the efficiency. Furthermore, below 5 m, the ash entrained with the gases will not be completely burnt, and will thus tend to adhere to the tubes, thus becoming harmful and dangerous. On the other hand, if the length of path for the gases is unnecessarily increased, there will be increased losses by radiation and by air leakage, as well as an increase in the space required and in the cost of the installations.

ii) Width of the boiler

The various types of water tube boilers generally have a given heating surface per unit width of furnace. For example:

Cail – Steinmuller boilers with headers: 110m²/m (360 sq.ft./ft) width

Fives – Stirling boilers with drums: 135 m²/m (443 sq.ft./ft) width

With recent installations, where the capacity is expressed in tones of steam per hour rather than in heating surface area, we have:

Fives Cail – Babcock boilers with BC1 type furnace: 5 t/h/m (1.5 t/h/ft.) of width

Fives Cail – Babcock boilers with spreader stokers, type BR1: 6 t/h/m (1.8 t/h/ft.) of width

To avoid the drawbacks of a complicated shape, the combustion chamber should have the same interior width as the boiler, and the total width of the furnace or furnaces should be atleast equal to the latter.

iii) Volume of combustion chamber

The volume of the combustion chamber should be proportioned to the volume of gases necessary for combustion. This volume is therefore fixed in relation to the quantity of heat

liberated per hour by the fuel used. Since a certain ratio exists between the heating surface of the boiler and the quantity of steam which it can produce, the combustion chamber volume may be related to the heating surface of the boiler.

The length, width and volume of the combustion chamber must conform to certain conditions, leaving little liberty to the designer of the furnace. The least imperative condition and the most elastic of the three is, however, that of the volume, which can, without great inconvenience, differ appreciably from the values given.

In all modern furnaces, there is provided, in addition to the normal air or primary air entering directly through the grate or by the tuyers (pipe through which air is blown into a furnace) of the hearth furnace, a complementary air supply for secondary air behind the bridge wall and consequently after the furnace proper. This air is introduced by a small duct built into the bridge wall. The introduction of this supplementary air for combustion has the object of ensuring complete combustion by changing to CO_2 the CO which may remain after combustion in the furnace. Secondary air is generally made 5-15% of the total air supplied, averaging 10%. There is no advantage in exceeding this amount; if combustion is good in the furnace, i.e. if the combustion temperature is high, it forms very little CO, and there would be risk of causing a useless increase in excess air.

Lesson 4. Bales, operation of baler, briquettes, advantages and uses of briquettes.

India, one of the most populous countries of the world (17% of world population) is also counted among the largest growing economies. However the pace its development is hampered by the inadequate availability of energy vital for sustainable growth. While its population is increasing at a rate of 1.5 %, the energy consumption growth is rising at a rate of 9% per annum and this demand is expected to double by 2020. Country with the capacity to generate 1, 23,668 MW of power has a shortfall of 15, 000- 20,000 MW currently. In fact the country has only solid fuel like coal as the main natural occurring resource of significance. But the higher percentage of ash content associated with it make it fuel of inferior quality. Hence the country is always on lookout for alternate fuels that can fill up the gap and help to meet the ever increasing energy demand.

Country generates large volume of agricultural residue that has good potential to be processed into a regular source of agro based fuel. Currently after separating the valuable grains, the residual biomass (70% in case of rice straw and 30% in case of wheat straw) is considered waste that is used by rural poor to fire its hearth. However processing of such biomass by suitable densification technique can convert it into briquettes that can not only generate income for farmer but also provide energy for commercial and industrial applications. A study conducted by CII has pointed out that country has tremendous potential for energy generation through biomass and its residue (Table 4.1)

Table 4.1: Potential of energy production from biomass in India

Potential in India (Excluding Co –generation)	16 000 MW
Installed capacity	630 MW
Project under consideration	630 MW

Source: CII- Godrej GBC publication RES-fact sheet- No 1   June 2004

Bale

A bale is unit of compressed biomass like straw, pine needles, cotton or any other bio-material that is pressed into a specific size and shape (e.g. Round, rectangular or square) so that its density is increase which is so vital for handling, transportation, storage and even usage. A baler is used to compress a cut and raked crop (such as, straw from different crops, cotton etc.,) into compact bale that are easy to handle, transport, and store. Several different types of balers are commonly used, each producing a different type of bales – rectangular or cylindrical, of various sizes, bound with twine, strapping or wire. Rectangular bales are easier to transport than round bales, since there is little risk of the bale rolling off the back of a flatbed trailer. The rectangular shape also saves space and allows a complete solid slab of hay to be stacked for transport and storage.

Fig.4.1 Rectangular bales

Operation of Baler

To form the bale, the material to be baled, (which is often hay or straw) in the windrow is lifted by tines in the baler's pickup. This material is then dragged into a chamber that runs the length of one side of the baler. A combination plunger and knife moves back and forth in the front end of this chamber. The knife, positioned just ahead of the plunger, cuts off the material at the spot where it enters the chamber from the pickup. The plunger rams the material rearwards, compressing it into the bales. A measuring device measures the amount of material that is being compressed and, at the appropriate length it triggers the mechanism (the knotter) that wraps the twine around the bale and ties it off. As the next bale is formed the tied one is driven out of the rear of the baling chamber onto the ground or onto a special wagon hooked to the rear of the baler. This process continues as long as there is material to be baled, and twine to tie with it.

Fig. 4.2 Balers

Bales of 30 x 30 x 60 cm (12 x 12 x 24 in.) or 45 x 45 x 60 cm (18 x 18 x 24 in.) are formed, and are tied with two or three wires, to prevent them from re-expanding. A hydraulic press is employed for this purpose, similar to a press for hay. The bales of biomass (e.g. bagasse, a sugarcane fiber residue after extraction of juice) have a density of 400-600 kg/m3 (25-40 lb. /cu.ft.), according to the pressure employed. They are then stacked in "draught board" fashion so as to allow air to circulate between the bales. In this way then dry more rapidly. However, this practice is discouraged in certain countries, such as the Philippines, where it is considered that it allows fire to spread more rapidly. On the other hand, it decreases the risk of spontaneous combustion. In two or three months, the bagasse loses part of its moisture, which decreases from 45-50% to about 25%, a value at which it becomes stable. The baggage bales then weight only about 300-400 kg/m^3)20-25 lb./cu.ft.). Bagasse is baled while moist, as it leaves the mills, can give rise to spontaneous combustion when stacked in a large pile. Bagasse baled and sticked in "draught board" fashion and sheltered from the weather may be

stored for a long time. When a long period of storage is foreseen, it is advantageous to sprinkle powdered boric acid on the stack proportionately as the stack is built up.

Briquettes

Briquettes are the eco-friendly renewable source of energy that avoids adding fossil carbon to the atmosphere. Biomass briquette is one which takes waste products such as saw dust etc and compresses it and extrudes it to make a reconstituted log which can replace the firewood. The natural lignin in the biomass binds the particles of wood/ agricultural residue together to form a solid. The burning of briquette is far more efficient than burning firewood as the moisture content briquette can be as low as 5% where as green firewood may contain as high as 65% moisture.

Biomass Briquettes are made from the agricultural waste, forest waste and industrial waste. The major residues are rice husk, coir pitch, jute sticks, sugarcane bagasse, groundnut shell, mustard stalks, cotton sticks, sawdust, caster shells/stalks, wood chips, bamboo dust, tobacco waste, tea waste, paddy straw, wheat straw, sunflower stalks, palm husk, soyabean husk, veneer residues, barks and straws, forestry waste etc.

Advantages of Briquettes

1. Eco- friendly and renewable energy fuel

2. Economical and cheaper than other solid fuels like wood and coal

3. Higher thermal calorific value (around 4000 Kcal/Kg)

4. Pollution free because there is no sulphur or any other hazardous materials.

5. Lower ash content (2 – 5) % and there is no fly ash when burnt.

6. They are of consistent quality, high burning efficiency due to low moisture content and uniform size.

7. Easy for transportation, feeding and combustion due to unique cylindrical shape

8. Low ash content (10%) in comparison to coal (25 – 40 %) resulting in less boiler ash disposal problems.

9. Briquettes are usually produced near the biomass production and consumption centre thus supplies don't depend on erratic transport from long distances.

10. Easy handling compared to loose agro waste having low bulk density.

Uses of briquettes in various industries

Gasifier system applications	Chemical industry
Leather industry	Rubber industry
Textile industry	Refractory industry
Dyeing units	Brick making units
Ceramic industry	Food processing industry

25

Any industrial thermal applications

A major disadvantage of agricultural residues as a fuel is their low bulk density, which makes handling difficult, transport and storage expensive, and gives rise to poor combustion properties. However, these problems can be overcome by compacting, with a compression ratio of approximately 7:1, the loose biomass to form briquettes.

Following are the few different densification techniques available:

1. **Piston press**

This press was developed in the Switzerland by Fred Hausmann. It consists of three main parts i.e. a die, a cylinder and piston and a driving unit consisting of a massive flywheel. The material is fed into the cylinder which is then compressed by piston into slightly tapering die. The legnins contained in the biomass begin to flow and act as a natural glue to bind the compressed material. When cylindrical material exit the die, legnins solidify and hold it together to form briquette which breaks into pieces 10-30 centimetres long. The diameter of the briquette is related to the capacity of the press. The pressure in the compression zone is in the range of 110 -140 MPa.

Capacity = Volume of material that can be fed in front of piston in each stroke X Number of stokes / time .Capacity by weight depends upon the density of material before compression.

Most of the units presently installed in India are of the reciprocating piston type, where the biomass is extruded through a die by a reciprocating ram at a very high pressure.

2. **Screw press**

This press was developed in USA in 1930. In this press biomass is fed continuously into a cylindrical die. The die is often heated to raise the temperature to the point where legnin flow occurred. Pressure builds up smoothly along the screw rather than discontinuously under impact of a piston. If die is not heated then temperature may not rise sufficiently to cause legnin flow and a binding material may have to be added. This can be molasses, starch or some other cheap organic material. If die is heated, then temperature is normally raised to 250 – 300 °C, which produces a good quality briquette from virtually all organic foods, provided the initial moisture is below 15%. The briquettes from screw press are often of higher quality than from piston press unit being harder and less likely to break along natural fracture lines.

Screw presses are usually sized in the range 75-250 kg/in though larger machines are available. The maintenance costs of screw presses are usually much higher because of the considerable wear on the screws which have to be re-built rather frequently. In terms of briquette quality and production procedure the screw press is superior. The briquettes produced by a screw extruder helps in uniform and efficient combustion, with significant reductions in smoke. Also these briquettes can be carbonized which increases their energy density.

3. Pellet press

Such machines were originally developed for the production of animal feed stuffs. In these rollers run over a perforated surface and material is pushed into a hole each time a roller pass over. The diameter of the briquette is very small (10- 30 mm). They are expensive and have high throughputs of 5-20 t/hr. for a single unit.

Facilities needed for value addition to biomass

1. Storage

Storage of raw material (agricultural residue) is likely to be in the form of open storage piles adjacent to the process plant. Normally there is no need to cover the pile. When processing dry matter, some kind of coverage is necessary in order to enable operation in the periods of rain. Generally tarpaulins and sheds will offer some storage. If a drier is included in the process, a storage bin must be installed for intermediate storage of dried material before Briquetting. The briquetted end product will always be stored under cover as briquettes will crumble and disintegrate if rained upon.

2. Handling

Handling normally makes up the largest group of equipment in large automated plants. However for a small mechanical piston press, the simple solution for handling briquettes is letting the machine push the material all the way to the product storage. Turns, even U-turns are possible since the material is still warm and rather soft.

3. Comminution

The need for size reduction depends upon the material. The density of briquette should be more than 1000 kg/m3 (i.e. individual briquette should sink in water). This density is set by the density of raw material. Density is also affected to a significant degree by the particle size of the raw material. Finely ground material will make dense briquette. Moisture content is another parameter which affects the density. All these factors are very important for briquetting paddy straw. So comminution is must in this case. This size reduction is carried out by hammer mill as it can crush the paddy straw into coarse fine fraction.

4. Classification

To insure that paddy straw after crushing is clean and contains no oversize particles, there must be screening operation. Normally over sized material is removed and sent back into the hammer mill. Mechanical piston press (commonly used in India) is especially sensitive to large particle entering the press.

5. Drying

The moisture content of the crushed paddy straw feed should not be more than 15%. So in case of higher moisture, thermal drying is commonly used. For this some of the briquettes are burnt to produce hot air to be used for drying raw material

6. Densification

This is the last stop for producing briquettes. Among the various methods ,mechanical piston press is preferred in the country.

Module 4. Thermo-chemical conversion of solid waste

Lesson 5. Biomass gasification, gasification process mechanism, types of gasifier reactors, utilization of producer gas

Biomass is any material produced through Carbon Dioxide fixation due to photosynthesis reaction in presence of sun light. In this process the sun energy is converted to carbohydrates stored in the plants as chemical energy. Wood and agricultural crop residues are some important biomass renewable energy sources. The biodegradable component of the Municipal Solid Waste, animal wastes and commercial and industrial wastes are also other significant biomass as renewable energy sources.

Biomass materials can be converted to other useful products through thermo-chemical, biological, chemical and mechanical conversion processes. The key difference in thermo-chemical and biological conversion processes is that the biological conversion is relatively slow process typically taking hours, day and weeks (anaerobic digestion, fermentation) or years (landfill gas by digestion) for reaction to be completed. Thermo-chemical conversion process gives multiple and complex products and takes place in short reaction time.
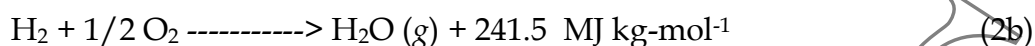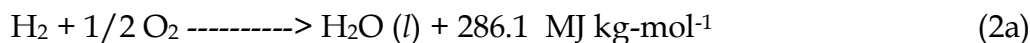
Biomass gasification

Gasification processes convert biomass into combustible gases that ideally contain all the energy originally present in the biomass. In practice, gasification can convert 60% to 90% of the energy in the biomass into energy in the gas. Gasification processes can be either direct (using air or oxygen) or indirect (transferring heat to the reactor from the outside). The gas can be burned to produce industrial heat, to run engines for mechanical or electrical power, or to make synthetic fuels.

Biomass gasification is already a well proven technology. Approximately one million downdraft gasifiers were used to operate cars, trucks, boats, trains, and electric generators in Europe during World War II. Development of biomass gasification was disrupted in 1946 as the war ended and inexpensive (15¢/gal) gasoline became available. The magnitude of damage inflicted on gasifier technology by this disruption can be seen by the fact that it is difficult for even the "advanced" technology of the 1980s to achieve on tests what was routine operation in the 1940s. The design, research, and manufacturing teams of that decade have all disbanded. We have from the past only that small fraction of knowledge that has been published, whereas the large bulk of firsthand experience in operation design has been lost and forgotten.

Gasification was rediscovered in an era of fuel shortages and higher oil prices, and there are gasifier engine projects under way in more than 20 countries for producing process heat and electrical and mechanical power. In its rebirth, however, the existing technology has uncovered major problems in connection with gasification reactor scaling factors, effluent and gas cleanup and the fuel supply, which were less important during the emergency of World War II. Today, these problems must be solved if biomass gasification is to reemerge as a fuel source.
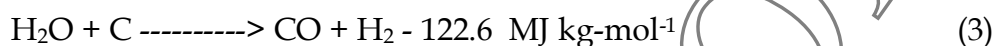
Gasification process mechanism

Different processes and operations occurring in the gasifier reactor are mainly in four reaction zones (i.e., oxidation, reduction, pyrolysis and drying). The sequence of reaction zones in a gasifier depends on the type of gasifier and direction of flow of fuel and air or gas. In the oxidation zone, carbon and hydrogen of the biomass are oxidized to carbon dioxide and water vapor in accordance with the following reactions.

$$C + O_2 \text{--------------> } CO_2 + 393.8 \text{ MJ kg-mol}^{-1} \tag{1}$$

$$H_2 + 1/2 \, O_2 \text{-----------> } H_2O \, (l) + 286.1 \text{ MJ kg-mol}^{-1} \tag{2a}$$

$$H_2 + 1/2 \, O_2 \text{-----------> } H_2O \, (g) + 241.5 \text{ MJ kg-mol}^{-1} \tag{2b}$$

Reactions 1 and 2a & 2b are the principal oxidation reactions. They are highly exothermic. Almost all the oxygen consumed in gasification process is used up in the oxidation zone. The temperature in the oxidation zone range from 800 to 1200 °C, depending upon the type of the gasifier and fuel. Carbon dioxide and water vapor leave oxidation zone at high temperature and move into reduction zone.

In reduction zone, carbon dioxide and water vapors are reduced to carbon monoxide, hydrogen and methane in accordance with the following reactions.
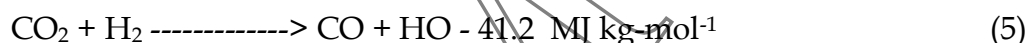
Water gas reaction:

$$H_2O + C \text{-----------> } CO + H_2 - 122.6 \text{ MJ kg-mol}^{-1} \tag{3}$$

Boudauard reaction:

$$CO_2 + C \text{-------------> } 2CO - 172.6 \text{ MJ kg-mol}^{-1} \tag{4}$$

Water gas shift reaction:

$$CO_2 + H_2 \text{-------------> } CO + HO - 41.2 \text{ MJ kg-mol}^{-1} \tag{5}$$

Methane formation reaction:

$$C + 2H_2 \text{--------------> } CH_4 + 75.0 \text{ MJ kg-mol}^{-1} \tag{6}$$

Reactions 3 to 6 are the principle reduction reactions and are reversible. For reaction 3 the equilibrium temperature is about 900 °C. The equilibrium temperature for reaction 4 is about 1100 °C. Optimum temperature for reactions 5 and 6 is 700 to 600 °C. It indicates that the higher reactor temperature during gasification process favors higher concentration of CO and H_2 in the producer gas. The low reactor temperature leads to higher methane concentration in producer gas.

Major reduction reactions (i.e., reactions 3, 4 and 5) are endothermic. Heat liberated in the oxidation zone of the gasifier is used for reduction reactions. The gas temperature drops from around 1000 °C in the oxidation zone to 450 °C at the end of the reduction zone.

Apart from the oxidation and reduction reactions, pyrolysis and drying also takes place in gasifiers. Pyrolysis takes place adjacent to the oxidation or reduction zones depending upon the type of gasifier in a temperature range of 200 to 500 °C.

Type of gasifier reactors

The gasifiers are usually classified on the basis of direction of fuel and air or gas flow in the reactor. The classification of gasification reactors often referred in the literature is given below:

Up draft

Down draft

Fluidized bed

Circulating fluidized bed

Entrained flow

Up draft gasifier

An up draft gasifier is characterised by a counter current flow of the fuel and air or gas in the reactor. Fuel is fed from the top and air is introduced at the bottom of the reactor. The producer gas exits from the top of the gasifier. Oxidation zone is formed at the bottom of the gasifier. The reduction, pyrolysis and drying zones are formed above the oxidation zone in sequence.

In an up draft gasifier, the producer gas passes through the low temperature pyrolysis and drying zone in the gasifier before exit. The tar released in pyrolysis zone and water vapours formed in drying zone move along with the producer gas unconverted. Thus the gas generated from an up draft gasifier contains high quantity of tar and moisture. The tar content of the producer gas varies from 1 to even 20 g/Nm^3. The gas is therefore considered suitable for thermal applications where removal of tar is not very essential. Up draft gasifiers generally, operate at high efficiency (hot gas basis) because of low gas temperature at the gasifier exit. Current R & D work in the country on up draft gasifiers, is mainly for thermal applications.

Down draft gasifier

Down draft gasifiers are characterized by co-current flow of air or gas and the fuel. In a dawn draft gasifier, normally fuel is introduced from the top while air is fed either from the top of the reactor or from the side, in the oxidation zone.

In a down draft gasifier, the pyrolysis products (i.e., tar and other condensable components) pass through high temperature oxidation and reduction zones. This is why, most of the tar is either burned or cracked thermally in the gasifier itself. The producer gas generated from a down draft gasifier has minimum quantity of tars and other condensable and is considered the best for engine operation. Down draft gasifiers can be further classified as down draft gasifier with throat and constant diameter throatless gasifier.

Down draft gasifier with throat

This gasifier has a narrow section below the air entrance point in the reactor which is called throat. Due to decrease in the cross-sectional area at the throat, the air or gas velocity increases resulting high and better temperature distribution in the oxidation zone.

In a down draft gasifier, pyrolysis zone is formed above the oxidation zone, whereas the reduction zone is formed below the oxidation zone.

This type of gasifier is highly fuel specific and operates only on wood chips, charcoal and selected woody agricultural crop residues. Its cold gas efficiency is about 75% at full load operation. These gasifiers are available in the capacity range of 2.5 to 250 kW.

Throatless gasifier

Down draft gasifier with throat produces best quality producer gas, but it is not suitable for gasification of paddy husk. Since paddy husk is an important agricultural crop residue having potential as an energy source, a throatless down draft gasifier was conceived for gasification of paddy husk. The reactor has a constant diameter without throat. The reaction zones sequence in this gasifier is similar to that of the down draft gasifier with throat. The reaction zones in a batch operated throatless gasifier are shown in Fig.5.1.

In batch operation, the residue/ash left after the gasification accumulates in the gasifier. The reaction zones thus keep on moving up in a throatless gasifier. However, in a continuous reactor where ash removal and material feeding are continuous, the reaction zones remain more or less at the same location. The cold gas efficiency of this gasifier varies from 55 to 65% depending upon the operating conditions. Throatless gasifier has been successfully operated using low density leafy biomass, for engine quality gas production.

Simple design, operation and maintenance of a batch operated throatless gasifier supports its use in remote village environment where high level technical skill and workshop facilities are not available. The gasifier can be used to run IC engine (5 to 20 hp) for farm irrigation or water pumping.
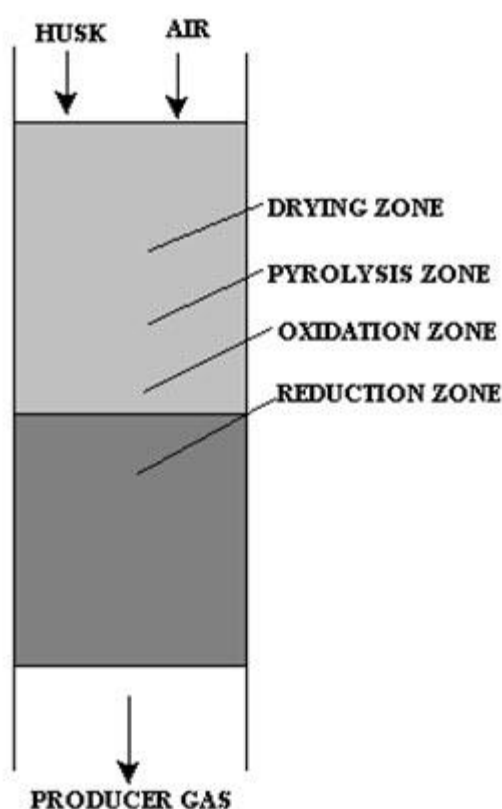

Fig. 5.1 Reaction zones in a throatless gasifier

Fluidized bed gasifier

Fluidized bed gasifier is a homogeneous reactor bed of inert sand material. Usually high alumina refractory sand is used as a bed material and fluidization is carried using air/gas. Usually ground or palletized biomass having uniform size is used in these gasifiers. The fuel is introduced in the inert bed material. Air is introduced through an air distributor at the bottom of the bed in the reactor. Oxidation, reduction pyrolysis processes occurs simultaneously. These gasifiers are available in higher capacity ranges (1 to 5 MW$_e$). The diameter of fluidized bed reactor may be selected in such a way that at maximum load the gas velocity is less than the terminal velocity of the bed smallest particle to avoid the carryover of the excess solid particles. At lower loads the velocity should be more than the largest particle otherwise the bed may get de-fluidized.

In fluidized bed gasifier a precise control of reactor temperature can be maintained at a desired level by adjusting air fuel ratio. So materials with high ash and low ash slagging temperature can also be gasified in a fluidized bed gasifier. As a matter of fact any type of fuel can be used in this type of gasifier provided that the material is of uniform and small size. This gasifier is characterized by high gas exit temperature, very high solid particulate matter in the gas and relatively low efficiency. The producer gas generated from a fluidized bed gasifier requires extensive cleaning for thermal as well as mechanical applications.

Circulating fluidized bed reactor

In a circulating fluidized bed reactor the diameter is reduced to increase the gas velocity above the terminal velocity of the smallest particle in the bed. Therefore, all the solids are taken out of the reactor along with the gas and captured in a cyclone. The solid particles from the down comer of the cyclone are re-circulated back to the reactor with a small purge of fresh air.

Utilization of producer gas

The producer gas is a mixture of Carbon dioxide, Hydrogen and Methane as combustible gas along with Nitrogen and Carbon dioxide. Typical producer gas characteristics are given in table 1. The gas has a heating value of 4.5 to 6 MJ/Nm^3 and can give a self sustaining flame on ignition. The gas can thus be used for various thermal applications such as boiler fuel and process heat energy in small/medium industries, cooking, welding etc. The gas can also be used a a supplementary fuel in an unaltered diesel engine and it can operate a spark ignition engine to produce mechanical power, which can be converted to electricity. In the following two case studies are indicated showing the electricity generation from a throateless rice husk operated gasifier and thermal application of gas from a down draft gasifier with throat. There gasifiers were developed and tested in the School of energy Studies for Agriculture, PAU, Ludhiana.

Producer gas composition:

Carbon Monoxide	20-22%
Hydrogen	12-18%
Methane	2-3 %
Carbon dioxide	8-12%

Nitrogen	45-55%
Oxygen	> 1%
Others	Tar, SPM,
Lower heating value of gas	4 to 5.5 MJ/Nm³

Throatless gasifier

The gasifier had capacity to generate gas for a 10 kW capacity diesel engine generator set. A schematic diagram of 10 kW gasifier engine system is shown in Fig.5.2.
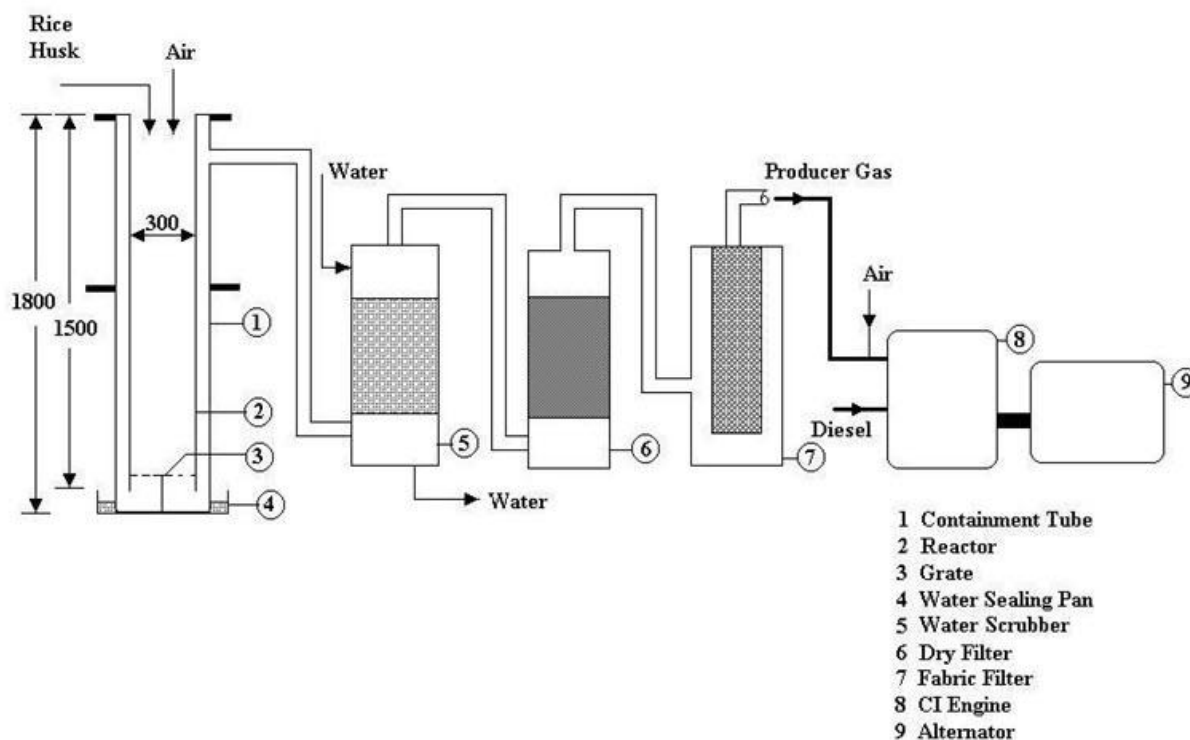
Fig .5.2 Line diagram of a 10 kW throatless gasifier engine system

The gasifier engine generator set was operated for 250 hours. On the basis of the operating experiences the performance evaluation of a 10 kW throatless gasifier engine is:

Capacity	10 kW
Gasifier efficiency	65%
Gas production rate	20 m³/h
Rice husk consumption	1.4 kg/kWh
Engine speed	1500 rpm
Diesel replacement	72%
Engine efficiency	26%
Exhaust gas temp.	450 ºC

Down draft gasifier with throat

Down draft gasifier with throat of different capacities ranging from 2.5 to 100 kW have been designed and developed in the School of Energy Studies for Agriculture, PAU, Ludhiana. The producer gas has been used for running un-altered diesel engines in dual fuel mode (producer gas and diesel) replacing about 70% diesel by producer gas. The gasifier have also been used for thermal applications in small industries replacing their oil/coal/wood fired furnaces. A schematic diagram of 20 kW gasifier gas burner system is shown in Figure.

1. Gasifier
2. Fuel feeding port
3. Condensate channel
4. Condensate collector
5. Air tuyeres
6. Heat exchanger
7. Ash port
8. Insulation
9. Fire port
10. Grate rotating handle
11. Producer gas inlet
12. Air inlet
13. Firing port
14. Flue gas exit

Dimensions in mm
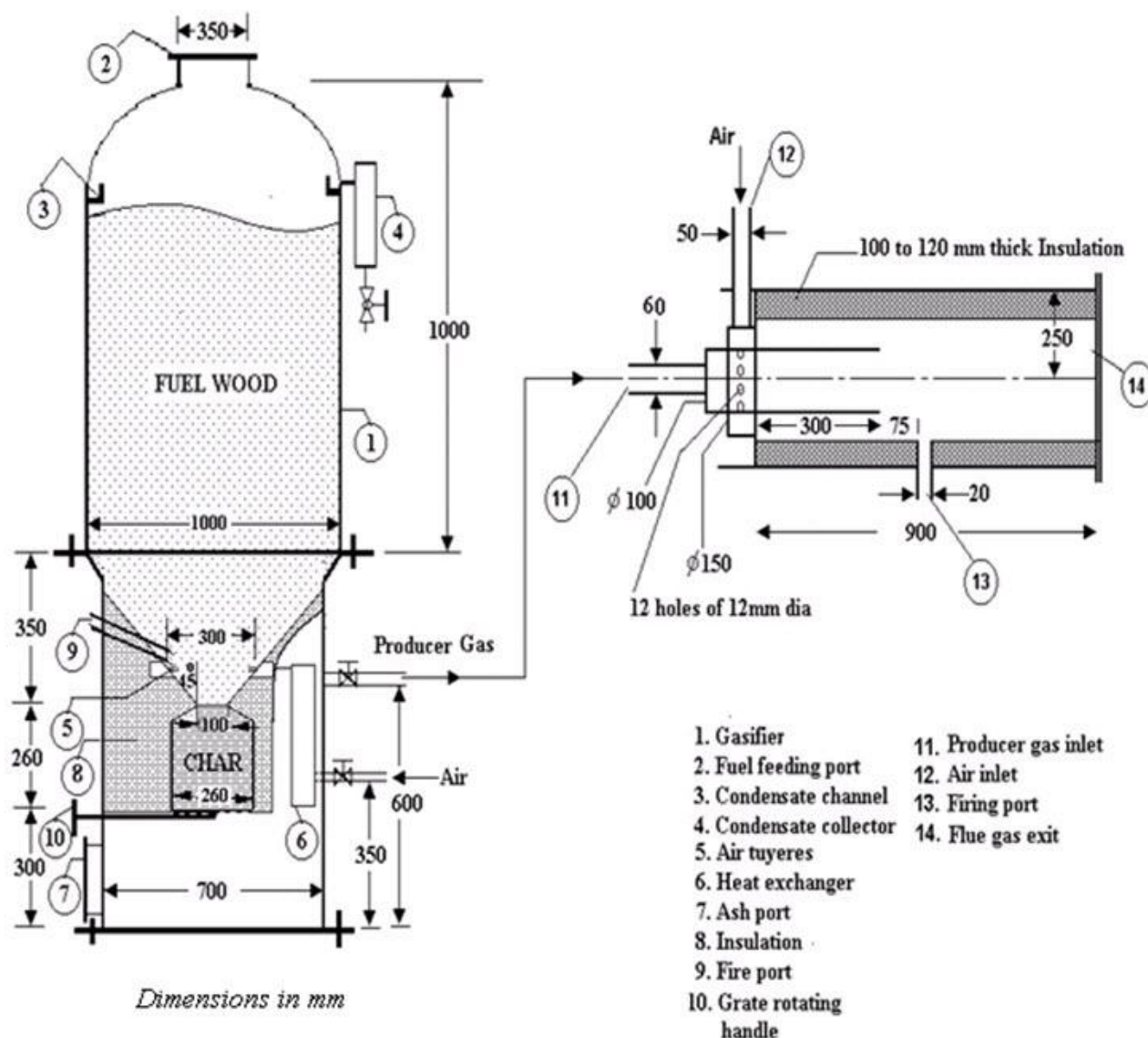
Fig. 5.3 Line diagram of a 80,000 kCAL/h capacity gasifier burner

Most of the biomass materials (crop residues, fuel wood species, agro-industrial residues etc) can be converted to producer gas via thermo-chemical conversion route by selecting appropriate type of gasification system. The producer gas is a low calorific value combustible gaseous fuel and can be used for thermal applications in industries. The gas can replace the liquid fuel in internal combustion engines i.e. partial replacement in an unaltered CI engine and total replacement in a SI engine.

Performance evaluation of a 80,000 kCal/h gasifier

Parameter	Value
Rated capacity	80,000 kCal/h or 20 kW$_e$ (approximately)
Biomass Feed Stock	
Name	Eucalyptus/any woody biomass
Size	30-45 mm
Moisture	8-12%
Consumption	22-24 kg/h
Producer Gas Flow rate	65 m^3/h at NTP
Average gas composition (Vol.)	
Hydrogen	14.38
Carbon monoxide	19.65
Carbon dioxide	9.32
Methane	1.98
Oxygen	2.72
Nitrogen	51.95
Heating Value of Producer Gas	1220 kCal/m^3
Producer gas temperature	250-400 ^{O}C
Gasifier efficiency (hot gas)	81.4%

Module 5. Bio-chemical conversion of solid waste

Lesson 6. Biogas, biogas plants, classification of biogas plants, design of biogas plants, comparison among KVIC, Janta and Deenbandhu biogas plants, working of Deenbandhu biogas plant.

Biogas

Anaerobic fermentation of cellulose containing organic material results in production of a combustible gas which is known as biogas. A number of stages are involved in the biogas production process. Initially organic material is hydrolyzed by enzymes into simple sugars, alcohol peptides and amino acids. These are then converted to volatile fatty acids, hydrogen, carbon dioxide, water and some amount of methane. Methane forming bacteria then converts the fatty acids into methane, carbon dioxide and water.

Constituents of biogas

- Methane (50-65%)

- Carbon dioxide (30-40%)

- Hydrogen (1-5%)

- Nitrogen (1%)

- Hydrogen sulphide (0.1%)

- Oxygen (0.1%)

- Water vapours (0.1%)

Biogas plant

The whole system in which anaerobic fermentation of cellulose containing organic material takes place and produces biogas, which accumulates in the gasholder or the dome, then utilization of this gas through the gas pipeline under suitable pressure is called biogas plant system.

Initially cow dung was mainly used as fermentable material for the production of biogas. The biogas plants in India were mostly popular by the name of gobar gas plant and these plants were of Khadi and Village Industries Commission (KVIC) design. This biogas plant consists of mainly two parts:

i) A digester or fermentation tank with an inlet and outlet chambers for the entry of fermentable mixture (cow dung and water in 1:1 ratio) in the form of slurry into the digester and exit of digested slurry. The outlet would also control to constant volume of slurry in the digester.

ii) A gas holder to collect biogas, so formed by fermentation in the digester. It would also help to maintain anaerobic condition in the digester.

Components of a biogas plant

A biogas plant consists of the following parts:

i) Foundation

ii) Digester

iii) Gas holder or gas storage masonry dome

iv) Mixing tank

v) Inlet chamber/pipe

vi) Outlet chamber/pipe

vii) Gas outlet, pipe, gate valve, gas distribution pipeline, water trap, fittings, gas stove, lamp and similar appliances which can run on biogas.

Classification of biogas plants

The biogas plants are mainly classified into three classes

1. Community biogas plants

2. Institutional biogas plants

3. Family size biogas plants

Community biogas plants

It is a plant to be used by a group of people as a community. These types of plants are installed by a Village Panchayat/Municipal Committee for any Village/Mohalla/Town/City. The biogas produced from this type of plant is distributed to the people living in that locality. The size of theses plants is recommended to be more than 15 m³ per day.

Institutional biogas plants

These types of biogas plants are installed by an institution such as religious institution like Gurudwara/Mandir/Gowshala or educational institution like School/College. The biogas produced from these plants is used for the respective institution. The size of these plants is recommended also to be more than 15 m³ per day.

Family size biogas plants

This type of biogas plants are installed at individual family level. The biogas from this type of biogas plants are used by the individual family. The size of these plants is recommended up to 6 m³ per day.

Designs of biogas plants

Anaerobic fermentation systems may be of standard or high rate design. The differences between the two, is mainly in the degree of control of the environmental factors, this design, may be single – stage or two stage system. In the two-stage digesters, the second tank acts as

a storage and solid stabilization tank, while the first tank is designed to provide optimum conditions for gasification. In our country, mainly single stage digesters are built.

There are mainly two types of designs of biogas plants :

1. Batch fed (periodic) system.

2. Daily fed (semi-continuous) system

1. Batch fed system

The main advantages of batch fed plants are:

(i) They require little or no daily attention.

(ii) Many diverse materials can be used e.g., corn stalks, leaves, bagasse from sugar mills and milling wastes from wheat, rice and other grains.

(iii) Where the biogas and bio-fertilizer producing requirement is strictly connected with a campaign period or where the availability of raw materials is seasonal and the gas is required in quantity for drying grains, a batch-fed plant serve the purpose.

(iv) When a batch fed digester is used in combination with a continuously fed biogas plant on a farm, each could be fed different raw materials and produce the same end products.

The disadvantages of these digesters are

(i) Although the liquid contents are drained away before unpacking, fumes of ammonia remain which could be harmful to health.

(ii) The spent damp material will still be fibrous as digestion does not break down the lignin, and will require further processing (turning) to create favorable conditions for aerobic bacteria.

(iii) Gas production is in batches. However, this can be over come by building a series of tanks and staggering the loading so that production from one tank will overlap the other. The same gas storage can be linked to each tank in turn.

(iv) These plants are not suited for small farms/farmers who do not have sufficient raw materials and resources.

2. Daily fed system

In these types of plants, mainly cattle dung (now other wastes are also being used) is used as the feed material. These plants are also called continuous systems and are in operation by a large number. The layout of this single stage continuous consists of an input holding tank or digester or the fermentation well, consisting of an underground masonry construction, an inlet pipe/chamber for input and an overflow arrangement (outlet displacement chamber) for residual slurry. For gas either a 'floating' top which acts as a gas holder or a fixed top from which gas can be piped to a separate gas-holder or to the point of use is provided. The final unit is a storage tank for residual slurry (depending upon the capacity of the biogas plant). The actual layout of these items is a matter for on-site decision depending upon the availability of water, point of use of gas and the residue system in use.

The size of the plant is governed by two factors. First factor is the daily amount of cattle or excreta of other animals produced and the detention or retention time (detention or retention time is the average length of time for which the substrate (feeding material) remains in the fermentation well or digester which varies in different designs. The second factor is the daily requirement of gas for a particular family based on the number of family members. If the gas is to be used for generation of power, calculations shall be have to be made for the amount of gas required for the H.P. of the engine and the number of hours, it is proposed to run.

Conventional models of daily fed biogas plants

There are two basic models of biogas plants popular in India:

1. Floating-drum type model biogas plants

2. Fixed-dome type model biogas plants

Floating drum type model biogas plants

These plants are commonly known as KVIC (Khadi Village and Industrial Commission) plants and were standardized in 1962 and are used widely even now. These plants have an underground well-shaped digester having inlet and outlet connections through pipes located at its bottom on either side of a partition wall. An inverted drum (gas holder) made of mild steel is placed in the digester which rests on the wedge shaped support and the guide frame at the level of the partition wall and moves up and down along a guide pipe with the accumulation and use of gas. The weight of the drum applies pressure on the gas to make it flow through the pipelines to the points of use. The different components of KVIC biogas plants are shown in Fig. 6.1.

The gasholder alone is the costliest component which accounts for about 40% of the total installation cost of biogas plant. It also needs to be painted regularly for protecting it against corrosion. These plants can be of any size to cater the needs of the users.

Fixed dome type model biogas plant

In spite of increasing popularity and acceptance of the KVIC biogas plants by the public, these biogas plants by and large beyond the reach of most rural people because of high increasing cost, short life of steel drum. So, there was an apparent need to have alternative inexpensive design to bring it within the reach of the rural population. Due to these reasons, the floating drum type biogas plants have been replaced with fixed dome biogas plants. These are :

i. Janta Model Biogas Plants

ii. Deenbandhu Model Biogas Plants

Janta model biogas plant

This is the first fixed-dome biogas plant was introduced in the form of the Janta Model Biogas Plant by Gobar Gas Research Station, Ajitwal in 1978. The main feature of this model is that the digester and the gas holder are integrated parts of brick masonry structure. The digester is made of a shallow well having a dome-shaped roof on it. The inlet and outlet tanks are connected with the digester through large chutes which are called displacement chambers. The gas pipe is fitted on the crown of the masonry dome and there is an opening on the outlet

wall of the outlet displacement chamber for the discharge of spent digested slurry. The size of these plants is limited to 15 m³ par day. The different components of Janta Model Biogas Plant are shown in Fig. 6.2.
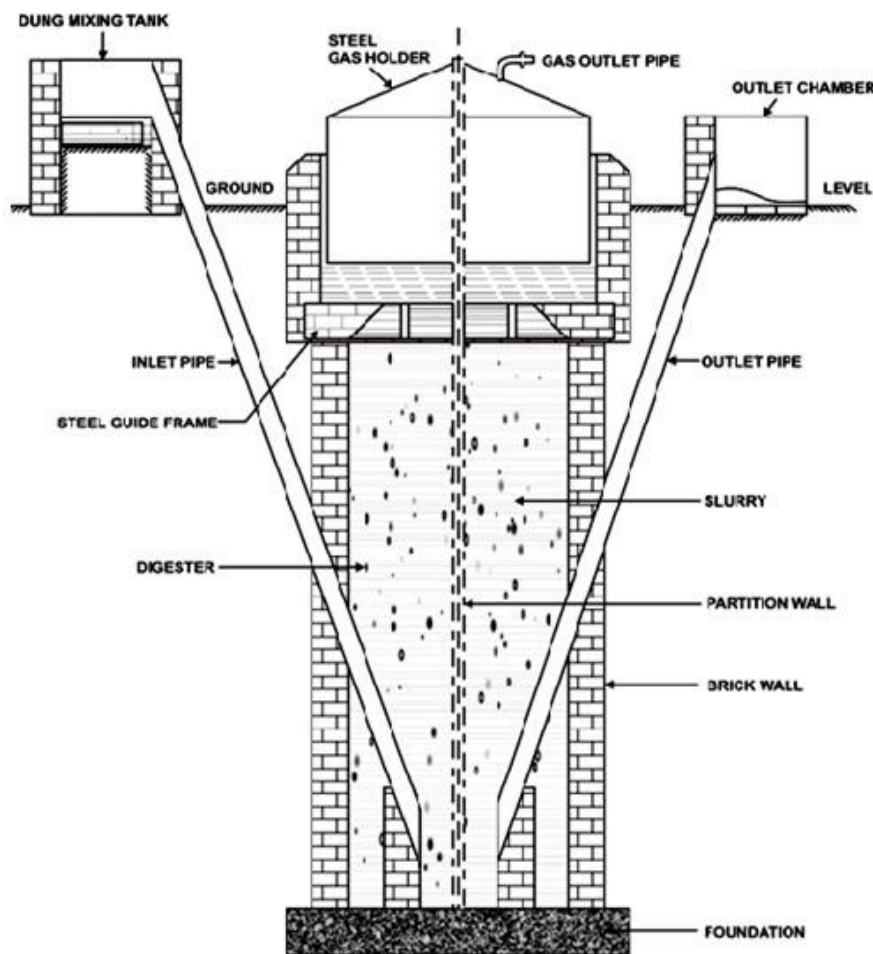

Fig. 6.1 KVIC model biogas plant

Deenbandhu model biogas plant

Deenbandhu model biogas plant was developed by AFPRO (Action for Food Production, New Delhi) in 1984. The world Deenbandhu is meant as the friend of the poor. This plant is designed on the principle that the surface area of biogas plants is reduced (minimized) to reduce their installation cost without sacrificing the efficiency of the plant. The design consists of segments of two spheres of different diameters, joined at their bases. The structure thus formed act as the digester as fermentation chamber as well as the gas storage chamber. The higher compressive strength of the brick masonry and concrete makes it preferable to go in for a structure which could always be kept under compression. A spherical structure loaded from the convex side will be under compression and therefore, the internal load will not have any residual effect on the structure.

The digester is connected with the inlet pipe and the outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced out of the digester with the generation and accumulation of biogas and is called outlet displacement chamber. The size of these plants is recommended up to 6 m³ par day. The different components of Deenbandhu Model Biogas Plant are show in Fig. 6.3.
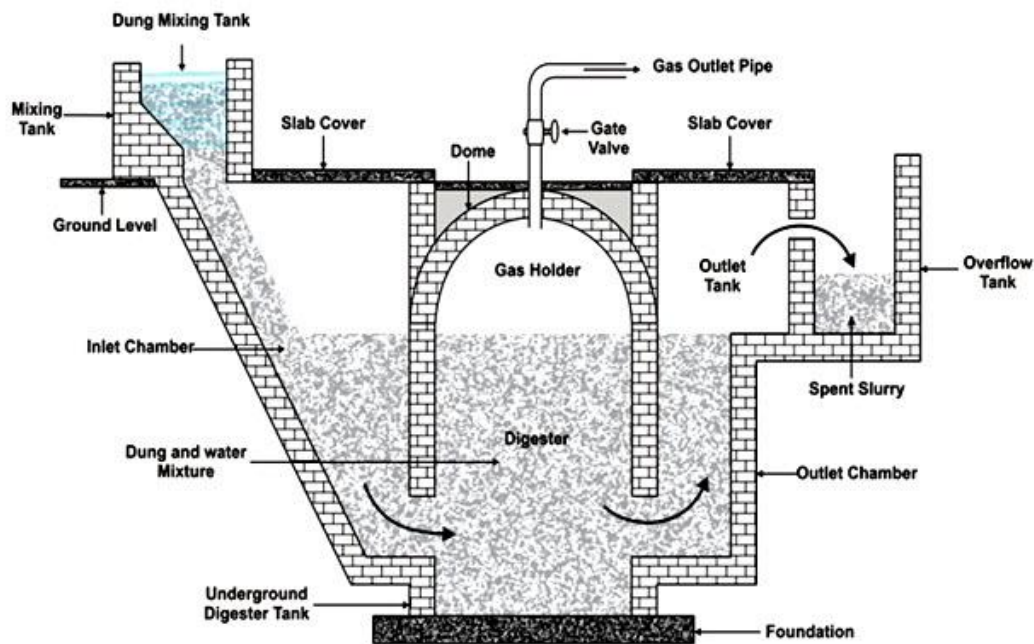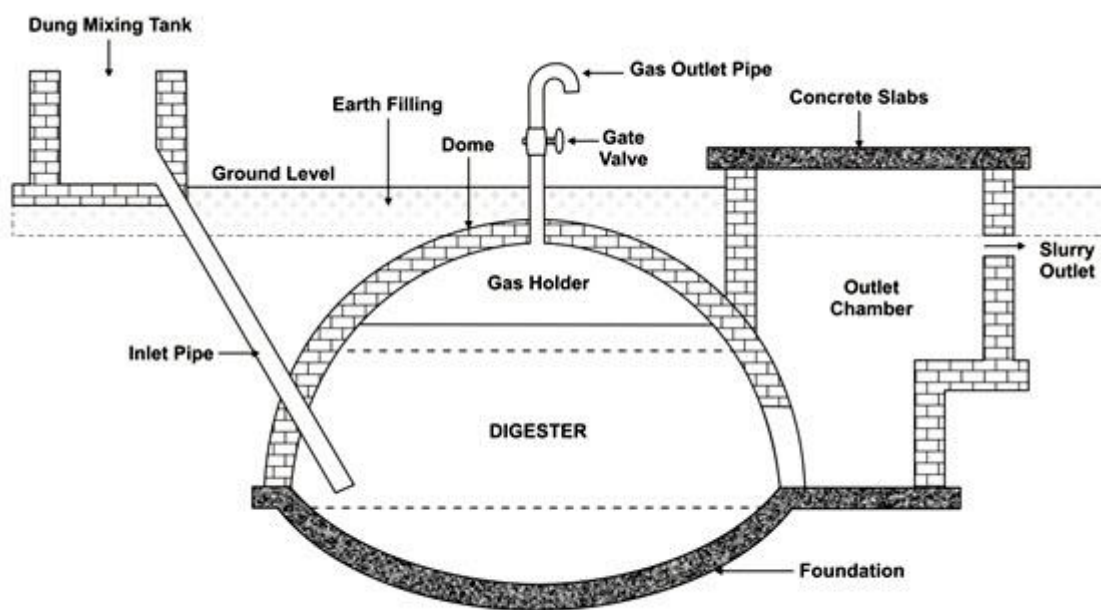
Fig. 6.2 Janta model biogas plant

Fig. 6.3 Deenbandhu model biogas plant

Comparison among KVIC, Janta and Deenbandhu biogas plants

Comparison among the above mentioned biogas plants is explained in Table 6.1

Table 6.1 Comparison between KVIC, Janata and Deenbandhu biogas plants

Sr. No.	KVIC	Janata	Deenbandhu
1.	The digester of this plant is a deep well shaped masonry structure. In plants of above 3m^3 capacity a partition wall is provided in middle of the digester.	Digester of this plant is a shallow well shaped masonry structure, No partition wall is provided.	Digester is made of segments of two spheres; one for the bottom and other for the top.
2.	Gas holder is generally made of mild steel. It is inverted into the digester and goes up and down with formation and utilization of gas.	Gas holder is an integral part of the masonry structure of the plant. Slurry from the gas storage portion is displaced out with the formation of gas and comes back when it is used.	The structure described above includes digester and the gas storage chamber. Gas is stored in the same way as in the case of Janata plants.
3.	The gas is available at a constant pressure of about 10 cm of water column.	Gas pressure varies from 0 to 90 cm of water column.	Gas pressure varies from 0 to 75 cm of water column.
4.	Inlet and outlet connections are provided through A.C pipes	Inlet and outlet tanks are large masonry structures designed to store the slurry displaced out of the digester with the formation of gas.	Inlet connection is through A.C pipe. Outlet tank is a large masonry tank designed to store slurry displaced out of the digester with the formation of gas.
5.	Gas storage capacity of the plant is governed by the volume of gas holder and is 50% of gas produced per day.	It is the combined volume of inlet and outlet displacement chambers and is 50% of gas produced per day.	It is the volume of outlet displacement chamber and is 33% of gas produced per day.
6.	The floating mild steel gas holder needs regular care and maintenance to prevent the gas holder from getting worn out because of corrosion. It also has short life span.	There is no moving part and hence no recurring expenditure. It also has long working life.	There is no moving part and hence no recurring expenditure. It also has a long working life.
7.	Installation cost is very high.	It is cheaper than the KVIC type plants.	It is much cheaper than KVIC and Janata type plants.
8.	Digester can be constructed locally but the gasholder needs sophisticated workshop facilities.	Entire plant can be built by a trained mason using locally available materials.	Entire plant can be built by a trained mason using locally available materials.

Working of biogas plant

Initially the digester is filled with a uniformly premixed mixture of dung and water (1:1 ratio) and the digester may be filled in three or four days or more time depending upon the availability of the dung. In order to facilitate gas production, addition of 5 to 10% inoculums, taken from a running biogas plant, will hasten the process by three to four days. In case no inoculums are available, sewage sludge can also be added. The first two or three installments of gas will not burn because of excessive CO_2.

When the cattle dung is used as feed stock, the biogas plant is to be filled with a homogenous slurry made from a fresh dung and water in a ratio of 1:1 up to the level of the second step in the outlet chamber (Fig. 6.4).

As the gas generates and accumulates in the empty portion of dome of the biogas plant, it presses down the slurry of the digester and displaces it into the outlet chamber. The slurry level in the digester falls, whereas in the outlet chamber, it starts rising with the formation of gas. This fall and rise continues till the level in the digester reaches the upper end of the outlet opening, and at this stage, the slurry level in the outlet chamber will be at the slurry outlet. Any gas produced after this stage will escape through the outlet chamber till the gas is not used.

When the gas is used, the slurry which was earlier displaced out of digester and stored in the outlet chamber begins to return into the digester. The difference in levels of slurry in digester and the outlet chamber exerts pressure on the gas which makes it flow through the gas outlet pipe to the points of utilization of biogas.
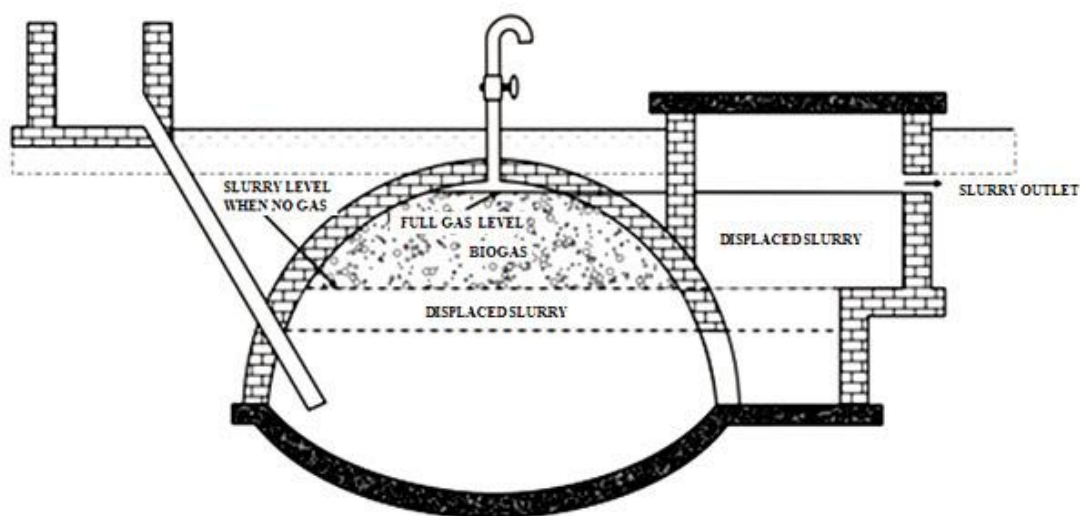

Fig 6.4 Working of Deenbandhu model biogas plant

Lesson 7. Selection of proper size of biogas plant, utilization of biogas for cooking purpose.

Selection of Proper Size

The size (capacity) of biogas plant means the quantity of biogas (in cubic metres or cubic feet) which we can get from it in 24 hours. The selection of proper size of a biogas plant is a very important to meet the required demand of biogas for use. The working of the biogas plant is directly linked with the size. The size of the biogas plant depends upon the number of cattle that a person or an institution would have. There is a minimum requirement of 40 kg of cattle dung for the smallest biogas plant. Normally, 10 to 20 kg of dung is collected from an ordinary cattle. Thus in view of this, it is considered that an average of 15 kg of cattle dung is collected from an animal. From one kg of cattle dung about 0.04 m^3 (1.4 ft^3) of biogas is collected. There is an requirement of about 0.34 to 0.42 m^3 (12 to 15 ft^3) of biogas for cooking of food per person per day. Biogas plant can also be operated on human excreta. But there is a requirement of minimum of 70 persons to run a smallest size of biogas size of biogas plant.

$$\text{Quantity of dung required per day for a biogas plant} = \frac{\text{Gas production/day}}{\text{Gas/kg of fresh dung}}$$

$$\text{No. of cattle required for a biogas plant per day} = \frac{\text{Total dung requirement}}{\text{Dung/cattle}}$$

Biogas other than cooking food can also be used for running diesel engine and producing light. Table 8.1 shows the requirement of biogas for different purposes. From this Table, the size of the biogas plant can be selected according to the requirement of biogas for a family e.g. if a family having 15-20 family members and this family has to utilize biogas for running diesel engine and producing light other than cooking purpose, then there is a need of minimum 15 m^3 size of biogas plant and for this size of biogas plant, the farmer will have to keep 25-30 animals.

Table 8.1 Required quantity of biogas for different purposes

Sr. No.	Purpose	Size	Required quantity of biogas (m³/hour)
1.	Cooking	5 cm burner	0.30
		10 cm burner	0.50
		15 cm burner	0.64
		per person/day	0.34-0.42
2.	Lighting	100 candle power lamp	0.13
		1 mantle lamp	0.07-0.08
		2 mantle lamp	0.14
		3 mantle lamp	0.17
3.	Diesel engine	1 H.P.	0.45-0.51
4.	Refrigerator	Per ft³ capacity	0.034
5.	Incubator	Per ft³ capacity	0.014-0.020

$$\text{Number of animals needed} = \frac{100\,l}{[fw\,d_f c_f + ew\,d_e\,c_e]}$$

where,

l = annual energy saving needed to recover investment, Rs. per year

w = average weight of animals, kg

f = net fuel replaced with biogas expressible as litre per day per 1000 kg live weight

e = net electricity produced from biogas, kwh per day per 1000 kg live weight.

c_f = cost of fuel in Rs. per litre.

c_e = cost of electricity in Rs. per kwh

d_e = Number of days when electricity is produced

d_f = Number of days when biogas is produced

Selection of proper hydraulic retention time (HRT), digester volume and size of gas holder

1. Hydraulic retention time (HRT)

The atmospheric temperature has great effect on the rate of biogas production in the digester. Low temperature would require more HRT and the digester size would be larger. Different zones of India have been set for having digesters of biogas plants with different hydraulic retention times.

Hydraulic retention time is recommended as below:

i) Plants based on 30 days HRT

This is recommended for states of Andhra Pradesh, Goa, Kerala, Karnataka, Maharashtra, Pondicherry and Tamil Naddu.

ii) Plants based on 40 days HRT

This is recommended for states of Bihar, Gujarat, haryana, Punjab, Jammu area of J & K State, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh and West Bengal.

iii) Plants based on 55 days HRT

This is recommended for states of Himachal Pradsh, North-estern states, Sikkim, Kashmir area of J & K state, hilly districts of Uttar pradesh and other hilly areas having long severe winters.

2. Digester volume

Digester volume for different size of biogas plants for different states of India having different HRTs is calculated as below :

Digester volume (V_1) for any size of biogas plant having HRT as H is

$$V_1 = \frac{(\text{Quantity of dung} + \text{quantity of water}) \times H}{\text{Density of slurry}}$$

Density of slurry = 1100 kg/m³

For example for 1m³ size of biogas plant having HRT as 40 days in Punjab, then V_1 is

$$V_1 = \frac{(25 + 25) \times 40}{1100} = 1.81 \text{ m}^3$$

The digester volume should be at least V_1. But there are presence of bubbles of gas in the digester, so increase about 10% of the volume of digester.

So digester volume (V) = $V_1 + 0.10\,V_1$

Therefore V for biogas plant in Punjab = 1.81 + 0.10 x 1.81 = 1.99 » 2m³

Therefore the volume of digester for any size of biogas plant can be calculated.

3. Size of gas holder

The biogas being produced in the digester is continuously used for sometime in the kitchen for household needs, so size of gas holder be smaller to save cost instead of its total storage. Thus, gas holder of a biogas plant is designed for less capacity as compared to the capacity (size) of biogas plants as follows :-

i.) Community/institutional biogas plants

For these plants, the size of gas holder is recommended from 50% to 70% of the size of biogas plant.

ii) Family size biogas plants

In India kitchen runs 8-12 hours a day, so the size of gas holders for KVIC model and Janta model are recommended as 50% of the capacity (size) of biogas plants whereas for Deenbandhu model, it is recommended as 33% of the size of biogas plants.

Utilization of biogas

Biogas being a very clean and good quality fuel, so it can be utilized for following purposes as:

Biogas for cooking purposes

Biogas provides a clean and efficient fuel for the kitchen, a special biogas burner (stove) other than L.P. burner is used for cooking purposes. It consists of nozzle, an air inlet, mixing chamber and fire sieve element. The nozzle is a hollow tube made of glass, metal, plastic or bamboo. As biogas passes through the nozzle, air is allowed to be drawn into the mixing chamber. For obtaining desired flame temperature, nozzle adjustment is done by trial and error. Biogas stoves normally operates at gas pressure of 7.5 to 9.0 cm of water column. Brightness and combustibility of gas can be maintained as 10:1. Combustibility of gas is maximum when flame is blue. Biogas cannot be burnt on LPG/Natural gas stoves as its nozzle is very small and would permit very little flow of gas.

Biogas can burn if the end of the discharge line is lighted, but this is inefficient and the heat release rate is low due to improper mixing of the air and fuel. The aim of designing a burner is to provide good mixing of air and fuel, to increase-the volumetric heat release rate, the combustion efficiency and heat transfer efficiency. The burner should ensure that the three T's of combustion are satisfied-temperature, turbulence and time. A good burner will help to produce intense temperature, regulate air supply, regulate the fuel supply and provide mixing of fuel and air. The air to fuel ratio in a burner can be adjusted by cutting the air supply and observing the flame. If incomplete combustion is observed, the air supply should be increased. Excess air should also be avoided as this lowers the combustion temperature and consequently some unburnt gas will flow out defeating the very purpose of excess air.

Biogas stoves should have the following characteristics:

1. Inlet channels should be smooth to reduce the resistance to flow of gas and air;

2. Spacing and size of air holder should be sufficient.

3. Volume in the channel where the gas and air mix should be large enough to allow complete mixing;

4. Gas jet holes should not be too large but should allow easy passage of the mixed gas and air;

5. The appliance should be simple, economical and easy to make.

6. While designing a biogas stove the following characteristics of the biogas are to be considered.

7. Composition of biogas (generally 60% methane and 40% carbon dioxide).

8. Pressure of the gas (8.75 - 10 cm water column).

9. Flame velocity.

The following rules should be observed while designing the biogas stove:

1. Air must be thoroughly mixed with gas before it reaches the flame ports and should flow near the gas jet, ideally with a venturi (In the absence of sufficient air there is a smell from burning gas).

2. Total area of the flame ports should be between 8-200 times the area of the gas jet. It may be noted that biogas stoves have large flame port diameters than stoves using LPG.

3. Distance from the flame ports to the surface of the cooking pot should be between 2.5 cm and 3.0 cm.

4. Supports for cooking pots should not prevent air from getting to the flame.

5. To allow cross-lighting from one flame port to the next, the distance between flame ports should not be more than 2.0 cm.

6. For corrosion-resistance properties, cast iron is better than mild steel.

Given below are the specifications for a 0.45 m^3 per hour common biogas stove for domestic use :

Jet size	2.25 mm dia
Area of jet.	3.98 mm^2
Flame port size	6.0 mm dia
Number of ports	20
Total area of ports	565 mm^2

Ratio of jet area to flame port area   1:142

Length of gas mixing pipe   20 mm

Diameter of gas mixing pipe   20 mm

Sustainability of flame is another important test to adjust the air to fuel ratio. If the flame does not sustain but is put off when the match stick is removed, it can be concluded that either the air supply or the fuel supply is in excess.

Design of biogas burners

A scheme diagram of the biogas burner is shown in Fig. 11.1. It consists of (i) an orifice for injecting the biogas (ii) an adjustable air port for air entry (iii) a chamber of thorough mixing of gas and air and (iv) ports for exit and burning of gas-air mixture.
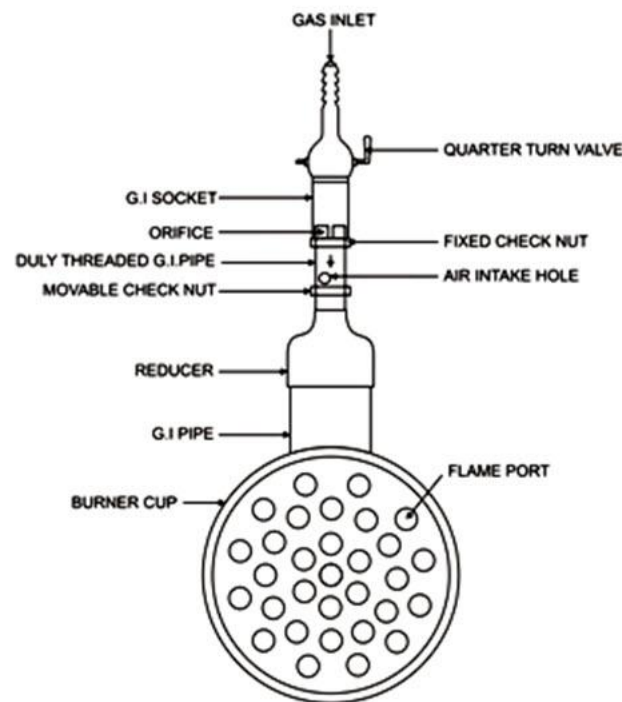
Fig. 7.1 Schematic diagram of biogas burner

The diameter of the orifice can be obtained by the equation.

$$Q = 3.6 \, C_d A_0 \, [2g \, (pw/pg)hg]^{1/2}$$

Where Q = gas flow rate (lit/hr)

C_d = coefficient of discharge (about 0.6)

A_0 = area of the orifice (cm²)

 g = acceleration due to gravity (981 cm/sec²)

pw = density of water (1000 kg/m³)

pg = density of gas (1.128 kg/m³)

hg = pressure of the gas (cm.w.g.)

For gas pressures of 5-10 cm. w.g., the orifice area per unit flow rate (A_0/Q) can be calculated to be about 0.01 mm^2 hr/lit. For higher pressures the above formula can be used.

Two 8 mm dia holes with an adjustable check-nut over them should be provided immediately after the orifice for air entry.

The mixing chamber should be about 15-20 cm. long. For high pressures, the length should be increased. The total area of the flame ports should be about 300 times the orifice area for proper flame propagation. Thus the diameter of each hole can be decided once the total number of holes is fixed. A total of 12 holes should be reasonable. The distance of the flame ports to the base of the utensil should be about 2.5 cm.

For cooking purposes, the following types of biogas burners can be used :

KVIC design burners

KVIC designed burners (utility type and deluxe biogas burners) are made of cast iron with injectors made of gun metal (Fig. 7.2). These two types of burners consume 0.45 m^3 of gas per hour which are adequate for 1-2 member and 5-6 member family, respectively. Initial pressure of gas in gas holder and burners vary from plant to plant. While designing these burners, initial pressure of gas in gas holder is assumed as 8.8 cm water column and in burner, between 7.6 cm and 8.3 cm water column. KVIC has also designed biogas burners for commercial use (for Dhabas, Hostel Messes etc), which are shown in Fig. 7.3.

Tin burners

These burners though not very efficient are made of tin to which gas is supplied from base pipelines (Fig. 11.4). Perforations are provided at upper portion of the tin to enable the gas to spurt out for burning. A number of small sized stones are kept outside to facilitate improved air and gas mixing. Tin burner can be embedded inside the earthern 'chulah' to suit flat bottomed and round bottomed cooking vessels.

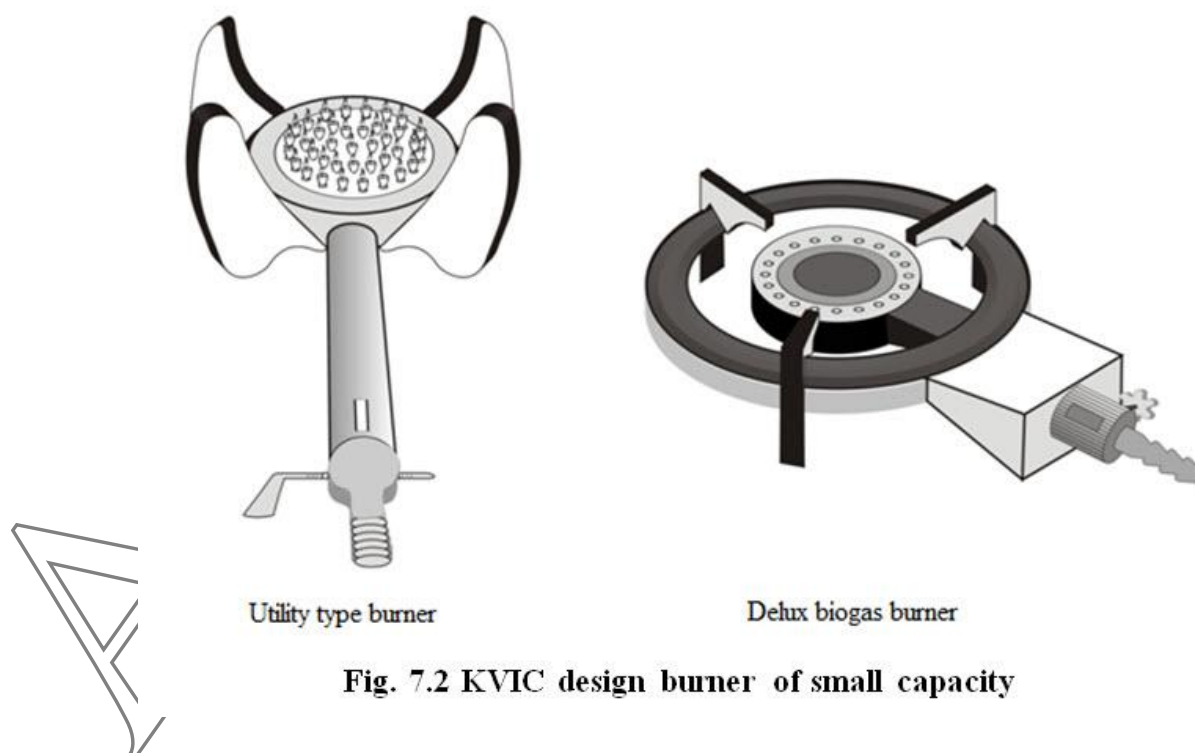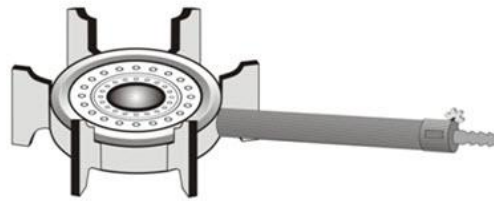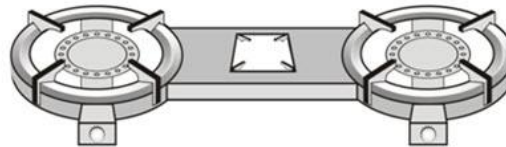Utility type burner   Delux biogas burner

Fig. 7.2 KVIC design burner of small capacity

(A) Biogas delux burner (450 liters/h capacity)

(B) Biogas angithi burner (1130 liters/h capacity)

(C) Biogas double delux burner (450 liters/h capacity for each burner)

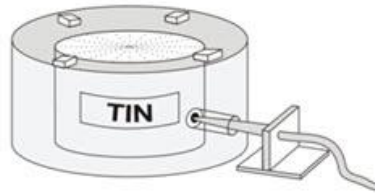**Fig. 7.3 KVIC design burner for commercial use**

TIN

Fig. 7.5 Biogas burner made from tin

Lesson 8. Utilization of biogas for lighting purposes and engine operation

Biogas as a lighting fuel

Biogas can be fed into any gas lamp using a mantle for lighting. Biogas lamp consists of nozzle, an air inlet, mixing chamber, mantle and glass globe. 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 (which is also used in making glass cloth and liner) and is coated with thorium nitrate solution. While burning, the Ramie fibre reduces to ash forming a layer of thorium dioxide which emits dazzling white light at high temperatures. Nozzle of this burner 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. As biogas passes through the nozzle, air is allowed to be drawn into the mixing chamber to freely mix with it. Brightness of biogas lamp mainly depends on factors like gas pressure, and relative proportion of gas and air which is about 1:10 and thoroughness in mixing. For achieving bright intensity, nozzle needle to be adjusted by trial and error. Low gas pressure causes poor light intensity, but higher pressure though it improves brightness but tends to lower mantle-life. Biogas lamps can be either suspended (hanging type) or put on table (standing type). As weight of biogas is almost half as that of air and as hot air flows upwards, brightness of a standing biogas lamp is somewhat greater than that of a hanging type. Biogas lamps are generally designed to produce 100 candle power (C.P.) and consume 0.11 to 0.15 m^3 biogas per hour.

In India, the biogas lamps are designed with single or double mantles. Both single and double mantel types can be further classified as internal or external types. An internal mantle lamp has a simple cover and is designed to produce 100 candle power (C.P.) which is equivalent to light intensity of 60 watts electric bulb. An external single mantle lamp has an outside protective cover to safeguard it from rain and wind and is also capable to produce same light intensity of 100 candle power. Designs of these two lamps are shown in Fig. 11.5 which works at gas pressure of 7.0 to 8.5 cm water column. A double mantle lamp can also be of both internal and external type. The internal type is fitted with a simple cover and can produce upto 100 candle power. The two mantle external type is equipped with a special cover to protect it from rain and wind and is also capable to produce 100 candle power (C.P.).

As for the starting sequence of the lamp, after opening gas cock and regulator, mantle is lit to light the lamp. Lamp can be turned-off by operating the gas cock. Regulator is adjusted for achieving requisite brightness. For preventing the possibility of any hazard, the lamp should be lit by bringing the match-stick close to the mantle either via the hole in the base of glass globe or via the reflector after opening it.
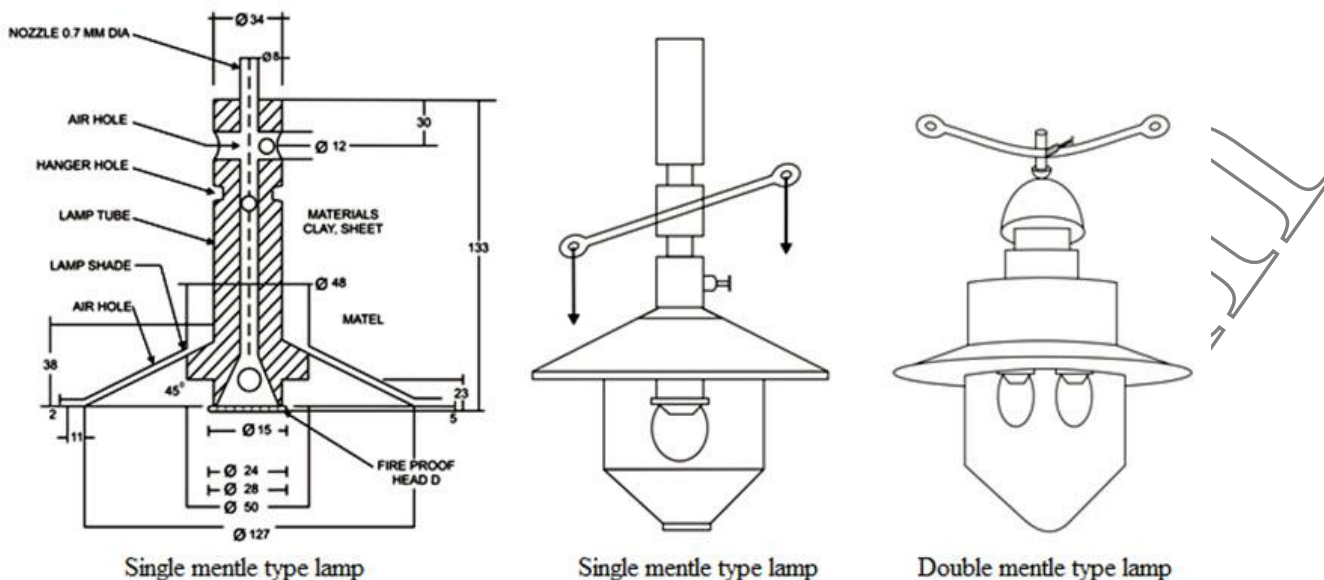
Fig. 8.1 Biogas fuelled lamps

Biogas for running dual fuel engines

Biogas as an engine fuel offers several advantages, biogas being a clean fuel causes smokeless combustion and reduced contamination of engine oil. It also reduces deposits on piston and combustion chamber. As gas needs is considerable, large capacity biogas plants are needed to supply gas for running IC (Internal Combustion) engines. It is to be noted that, even a 5 H.P. engine for 8 hourly operation requires gas supply from a biogas plant of 15 m³/day capacity. Community biogas plants with a gas output of 50 m³ per day are generally used to drive biogas fuelled electricity generating sets.

Normal consumption rate of biogas for running IC engines is 0.45 to 0.54 m³/hour/H.P. or 0.60 to 0.70 m³/hour kW if used for power generation. Biogas pressure is found to vary from 2.5 to 10.0 cm water column. If an engine consumes 0.50 m³ of biogas/hour/H.P., then quantity of engine consumes 0.50 m³ of biogas/hour/H.P., then quantity of gas needed for running a 10 H.P. engine for 10 hour operation per day becomes.

$$= (0.50 \text{ m}^3/\text{hour}/\text{H.P.}) \times 10 \times 10 = 50 \text{ m}^3.$$

Norms of biogas consumption for operating different capacity engines on dual-fuel are given in Table 8.1. These ratios are based on 8 hourly operation with 75 per cent plant efficiency with biogas consumption rate being 0.257 m³/H.P./ hour having 50 per cent diesel replacement with biogas, although replacement of diesel can be as high as 80 per cent.

Table 8.1 Rates of biogas consumption for operating different capacity engines on dual-fuel

S. No.	Engine rating H.P.	Biogas consumption (m³/day)	Capacity of plant to supply biogas (m³/day)
1.	5	360	480
2.	10	720	960
3.	15	1080	1440
4.	20	1440	1920

During the operation of an diesel engine, it is noted, when the piston moves downward during first stroke, then the inlet value opens and the fresh air is filled in the cylinder which enters through the air cleaner. In the second stroke, the piston moves upwards, then both the valves are closed and the air which is already entered in the cylinder is being compressed upto the ratio 17:1. Due to this compression, temperature of air is very much raised. After that the diesel is being injected into this hot air which catches fire and the piston again moves downward due to the high pressure of air. In the fourth stroke, the exhaust valve opens and the fuel gases are exhausted outside due to upward movement of the piston. Thus it is very clear from the operation of diesel engine that small quantity of diesel should be must for ignition. Due to this reason, a dual-fuel engine is first started with diesel fuel only. After it has attained normal running for some time, biogas choke is opened to admit gas into the combustion chamber. Biogas combustion can be controlled by adjusting the choke. In a steady engine operation, dual-fuel achieves nearly 75 per cent saving in diesel consumption. For stopping dual-fuel engine, biogas choke should be stopped first followed by throttle.

To run diesel engine on biogas, the biogas pipe is joined with the air cleaner of the engine to prepare the mixture of biogas and air. In the first stroke of the piston, the engine sucks biogas and air and it catches fire after injecting the diesel by the nozzle. A special and simple instrument shown in Fig. 8.2 can also be used to prepare the mixture of biogas and air and is joined with the diesel engine at modified inlet. The control of biogas is being done with the help of gate valve attached to this instrument.
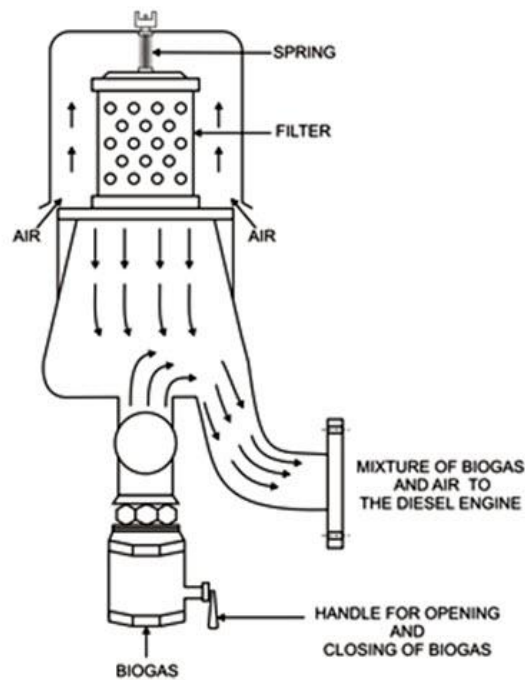
Fig. 8.2 Carburetor for diesel engine running on biogas

Methane, the lightest organic gas, has two fundamental drawbacks to its use in heat engines: it has a relatively low fuel value and it takes nearly 34450kP$_a$ pressure to liquefy it for easy storage, (2.48 m^3 of methane gas can be converted to 4.55 litre of liquid methane). So a great deal of storage of methane is required for a given amount of work. For comparison, propane liquefies around 1722.5kP$_a$.

Modified petrol engines

A petrol engine can be modified to run on biogas by drilling a hole in the carburetor near the choke. A tube is then inserted which is connected to the gas through a control valve. The engine is to be started on petrol and then switched on to run on biogas only.

In some cases, gas is admitted into the inducted air through a cam operated valve. A governor controlled disc regulates the quantity of gas admitted in accordance with the engine output. The governor also throttles the air supply so that the gas air mixture is within the ignition limits.

Typically a 4-stroke single cylinder 1 BHP engine running at 1800 rpm needs a biogas supply line of 9 mm diameter and gas pressure of 50 to 100 mm of water. The power developed is 85% of the older rating. The gas consumption is 0.51 m^3/h at full load and air to fuel ratio is 5.83 :1 at full load and 5.75:1 at normal load. The engine dissipates more heat than a conventional engine and the cooling system must be preferably water cooled.

Modifications
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 valve can be provided on the air cleaner pipe connecting the air cleaner and carburetor for throttling of intake air. In this case the intake air is required to be manually throttled in the initial stage.

Modified diesel engines (The dual fuel engine)

A diesel engine can be easily converted to run on 80 to 90% biogas and 20% to 10% diesel by feeding the gas in between the air intake and the engine. After the engine is started on diesel oil, the gas valve is opened gradually and the engine's governor automatically reduces the intake of diesel oil. Since the compression of the gas-air mixture is not sufficient to produce the temperature required for ignition, there is no danger of pre-ignition.

CI 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 thorough mixing of biogas with air before entering into the cylinder. The arrangements largely used in stationary engines commercially available in India. The capacity of mixing chamber may be kept equal to the engine displacement volume. The pilot injection of diesel in the cycle is required to be advanced for smooth and efficient running of engine on dual fuel.

Biogas for electricity generation

Biogas can be used to produce electricity by coupling a dual-fuel engine to an asynchronous generator. Based on results of several studies carried out. 1 kWh of electricity can be generated from 0.75 m³ of gas which can light 25 electric bulbs of 40 w rating whereas 0.75 m³ of gas if directly burnt can light only 7 biogas lamps for one hour. Hence it is advantageous to first generate electricity and then light larger number of electric bulbs. In China asynchronous generators of 3, 3.5 and 7.5 kW rating coupled to biogas-based IC engines are commonly used. However, electricity generation from biogas is economical only when gas is supplied by large community plants but it requires high initial capital investment. Decentralized power systems can be cost-effective especially when they minimize transmission and distribution costs. For cost-effective system, unit cost of biogas-based electricity should be less than supplied by the electricity boards.

Biogas in boilers and water heaters

Biogas successfully fueled the boiler that heated the digester chamber. Preliminary tests were made of its usefulness as fuel for a household-type water heater and for operating spark-ignition and compression-ignition internal-combustion engines.

The gas-fired cast-iron boiler was of commercial manufacture, of a type that would normally be fueled with LP gas. Several changes were required to prepare the unit for fueling with biogas:

- The diameter of the nozzle orifice was increased. The heating value of biogas is only 30 per cent that of LP gas and only 60 per cent that of natural gas, and line pressures were less with biogas than with LP gas. Consequently, the diameter of the burner nozzle orifices was enlarged approximately 70 per cent of biogas utilization.

- Air supply to the burner was decreased. The air-inlet ports had to be almost completely closed, which required special covers for the air inlets.

- Moisture was removed. A system of cooling and heating the gas in combination with condensate traps facilitated delivery of the gas to valves and orifices without risk of

condensation in these narrow channels. pressure-regulator valves were kept warm to prevent condensation.

- An independent fuel source (LP gas) was used for the pilot light. This was because the quality and supply of biogas may not be totally reliable. The pilot light required approximately 0.45 kg LP gas per day.

A 40-gal (150-liter) water heater was operated experimentally, using biogas as fuel. This test indicated that a gas consumption of 40 liter/min of water from 10 to 65°C. This corresponds to a thermal efficiency of 65 per cent, compared to a rated efficiency of 70 per cent. Further adjustment of the burner would probably improve its performance when fueled with biogas.

Since well-adjusted and fully loaded boilers and other water-heating devices may be assumed to have 70 per cent efficiency on biogas, as well as on other gaseous fuels, the fuel consumption for a water heater can be calculated from the relationship that 3.2 m³ of biogas 62 MJ will heat 190 liter of water from 50 to 10 to 65°C. In a home-heating system, 5.2 m³/h of biogas would give a rated (input) heating capacity of 29 kW.

Biogas use in stationary power plants

Biogas can be used in both spark ignition engines and compression ignition engines. The choice of the engine depends on the following factors:

(a) If the gas supply is assured, a S.I. engine can be used.

(b) If the gas supply is not assured, a C.I. engine with dual fuel operation can be used. This engine can run completely on diesel when gas is not available.

Biogas can be used in stationary power plants in the following modes :

(i) In a spark ignition engine by using a higher compression ratio with magneto ignition and modifying the carburetor system.

(ii) In a compression ignition engine with gas injection and pilot diesel injection. This requires biogas at high pressure. This is not generally used.

(iii) As a dual engine with diesel and biogas. Also dual fuel engine with petrol and biogas can be used, but this require relatively greater modifications.

(iv) In dual fuel gas turbines.

The following points be noted:

(a) Purification of gas by separation of H_2S prevents corrosion. Removal of H_2S prolongs engine life. Exhaust would be free of sulphur compounds.

(b) Removal of CO_2 by scrubbing the gas through lime water improves the calorific value by 30% on volume basis. Volumetric efficiency would improve and also higher specific output can be obtained.

(c) Gas burn carburetor for controlling intake of gas and air would be preferable.

(d) Regulation of engine cooling water flow rate would be desirable as the engines dissipate more heat than conventional engines.

(e) Use of biogas receiver bag for maintaining a constant pressure and flow rate may be considered. This consists of a cylindrical tube of 300 mm length and 75 mm diameter with a half return valve on the outlet side and a wire netting ball at the constriction point of cylinder outlet tube.

(f) Slow speed engines should be preferred.

(g) Ignition/injection timing advance to be set optimally.

Biogas in gas turbines

The main advantage of the use of gas turbines is that the capital cost is considerably lower compared to reciprocating engines-particularly when used aircraft engines whose normal flying duty is over are utilized. There are additional advantages of easy installation, modular maintenance, quick starting and reliable operation. National Aerospace Laboratory has studied the applications of Rolls Royee 'Dart' Engines used by IAF and Indian Airlines to provide mechanical energy for 1.0 to 2.5 MW electrical generators. These can be operated on dual fuels [biogas + diesel or kerosene]. This approach seems to be promising.

The production of electrical energy only by biogas fuel is not economical. However, cogeneration with I.C. engine connected with a generator and with waste heat recovery would be economical. The waste heat recovered can be cycled for digester heating.

Biogas in refrigerators

Biogas can be used in absorption refrigeration system without any problems as long as assured gas supply for burner is available. For a Refrigerator of 230 litres capacity, the biogas consumption will be approximately 0.044 m^3/l.

Particular problems also arise with biogas operated refrigerators. The composition of biogas varies substantially from day to day. The gas pressure fluctuates excessively with the amount of gas stored even in a floating drum plant. Special, stable-burning jets are therefore needed-especially if the refrigerator is thermostatically controlled and the flame burns only when required. On every ignition there is a risk of the flame going cut. Gas will then discharge without burning. The gas supply must therefore automatically be cut off if the flame goes out.

Small scale dairies handling 500 litres of milk per day seems to be feasible units for the rural setup. It is assumed that water is available in abundance and cooling of the milk from pasteurizing temperature of about 70°C to, say, 35°C can be done with the available cold water. Heat to be removed by water (taking the specific gravity and specific heat of milk as 1.03 and 0.95) is 500 x 1.03 x 0.95 x 35 = 17124 kcal.

For a raise in temperature of water of 5°C, the amount of water necessary = 17124/5 = 3425 kg.

Taking 4hrs.period for cooling, the required water flow rate = 3425/4 = 856 kg/hr.

For a 10m delivery head of water and a pump efficiency of 50%, the shaft HP required for the circulation pump = 856 x 10/(60x4500x0.5) = 0.06.

To cool the milk from 35°C to 3°C heat to be removed

= 500 x 1.03 x 0.95 x (35 - 3) = 15656 kcal.

Assuming 30% heat loss actual heat to be removed at the evaporator = 20 353 kcal.

Considering 8 hrs. operating time the refrigerating capacity needed

= 20353/(8x60x50) = 0.848 tons.

For a 3 m x 3m x 3m walk in cold storage the approximate cooling required would be 0.6 tons of refrigeration.

Total cooling capacity needed for the dairy = 1.448 tons. Hence the engine power needed for the dairy plant is approximately 2 hrs. Biogas out put needed for a dual fuel diesel engine for the above purpose = 4 m^3/day. For a spark ignition engine running totally on biogas the gas out put needed is 6.4 m^3/day. This would necessitate output from over 15 cattle heads.

Module 6. Solid waste management

Lesson 9. Methods of disposal solid waste, Vermin composting

Food industries produce a substantial amount of pollution especially in the form of solids. So solid waste management is very important for industrial growth and environmental concerns. The main impact of solid pollutants is

- Unnecessary use of land

- Spread of diseases

- Contamination of ground water

The management of industrial waste is comparatively easy as compared to municipal waste because of uniformly of the waste. The quantity and type of waste from agro-processing industry varies from unit to unit. The total quantity of solid waste generation is approx 50%of the quantity being processed. At present these waste are either dumped or sold as animal feed. The organic waste generated from various foods, sugar, coffee etc. have potential for bio-methanation.

The various methods of disposal are:

1. Landfills

2. Incineration

3. Compositing etc.

These methods are capable of degrade concentrated and difficult substrates like plant residues, animal waste, food industry wastes etc each method is having its advantage and disadvantages.

The environmental act 1995 states the following objectives for the treatment of wastes.

1. It should be ensured that waste is recovered or disposed off without endangering human health and without using methods which could harm the environment.

2. Best available technology at low cost should be used.

3. Ensure self-sufficiency in waste disposal.

4. The recovery of waste by means of recycling, re-use or reclamation and the use of waste as a source of energy must be encouraged.

Landfills

Landfills are primarily used for waste disposal, allowing nature to take its course. During the process of degradation, end volume and toxicity of wastes is used. The processes of degradation of organic bioactive waste in landfills involve not only biological processes, but

also interrelated physical and chemical processes. The organic components of the waste are degraded by m/o's in the landfills. The organic component could be protein, carbohydrates, lipids or fats. Carbohydrates are by for the major component of biogradable waste and include cellulose, starch and sugars. Proteins are large complex organic material composed of hundreds or thousands of amino-acid groups.

Lipids or facts are materials containing fatty acids. So landfill consists of 5 main steps

1. Hydrolysis/ aerobic degradation

2. Hydrolysis and fermentation

3. Acetogenesis

4. Methanogenesis

5. Oxidation

There are various factors which influence the degradation of the waste. These are

- Site characteristics

- Waste characteristics

- Moisture content of waste

- Temperature

- Acidity

The modern site is seen in this content as a 'bioreactor' used to stabilize waste and produce landfill gas for energy recovery. The amount of landfill gas generated throughout the lifetime of the landfill site as highly variable (i.e 39-500 m³/tone).

Landfills are not very desired disposal method because of following regulations:

1. Stringent environmental regulations concerning air quality.

2. Around water contamination.

3. Decreasing availability of land.

The methods followed in India are not keeping with modern practices of sanitary landfilling. The wastes are largely dumped in low lying areas which are prone to flooding.

Incineration

An alternative to landfills is incineration i.e waste containing combustible material is incinerated or combusted. It is the oxidation of the combustible material in the waste to produce heat, water vapour, nitrogen, carbon dioxide and oxygen. Depending upon the composition of waste, other emission may be formed like carbon monoxide, hydrogen chloride, hydrogen fluoride, nitrogen oxides, sulfur dioxide, volatile organic carbon, dioxins and furns, polychlorinated biphenyls, heavy metals. Incineration is a treatment route which can be applied to a wide variety of waste.

Advantages of incineration over landfill

1. It can be carried out near point of waste collection.

2. The waste is reduced to a biologically sterile ash product.

3. It produces no methane unlike landfill

4. Waste incineration can be used as a low cost source of energy.

5. The bottom ash residues can be used for material recovery or secondary aggregates in construction.

6. It is the best practicable environmental option for hazardous wastes.

Disadvantages of incineration

1. Much higher costs and longer pay-back periods.

2. Lack of flexibility

3. Removal of paper and plastics for recycling may reduce the overall calorific value.

4. Emitted levels may still have an adverse effect on health.

Compositing

Compositing is the aerobic rather than anaerobic, biological degradation of organic waste such as garden and food waste.

It is relatively fast biodegradation process, taking typically about 4-6 weeks to reach a stabilized product.

The main factors influencing composting are

1. Suitable oxygen

2. Temperature (30-35°C)

3. Moisture content 50-60%

4. pH range 5.5-8

5. CN ratio of material 25:1

6. Size range of waste material

During compositing organic matter is placed in piles that allow ventilation and the matter is stabilized by natural biological processes.

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   │                 │
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   │        │ High rate composting │
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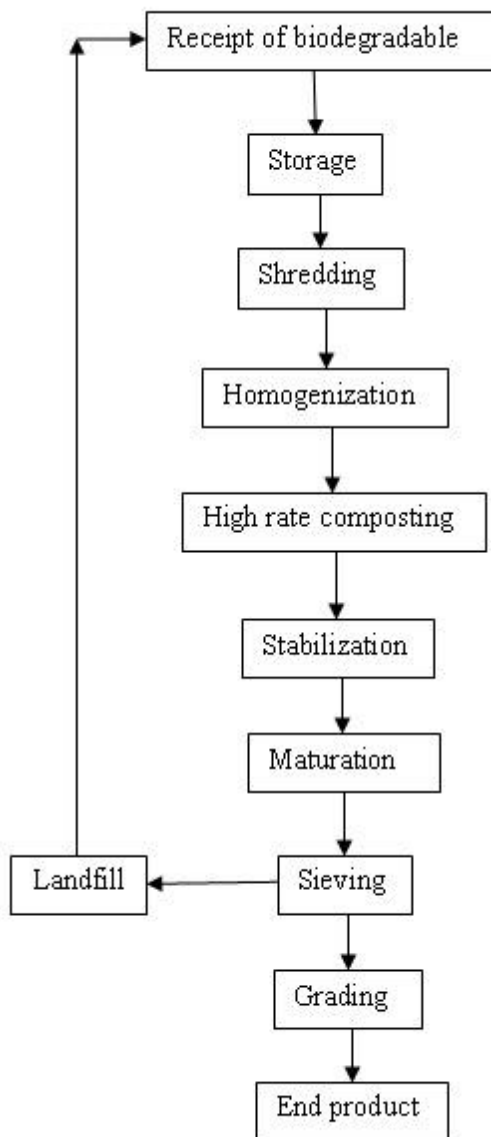
The process designs used in composting are

1. Aerated static pile composting

2. Mechanically agitated in-vessel composting

3. Windrow composting

1. Aerated static pile composting

Compost is formed into piles and aerated with blowers or vaccum pumps. The aerated static pile method of composting was developed in the mid-1970s to reduce land area requirements and to resolve other problems associated with the turned windrow method.

2. Mechanically agitated in-vessel composting

Compost is placed in a reactor vessel where it is mixed and aerated. Two basic types of reactors are used in vessel composting:

1. Vertical flow reactors:-

2. Horizontal or inclined reactors.

In vertical flow reactors the mixture is fed in at the top of the reactor on either a continous, intermittent or batch basis and can be agitated on its moving down the teactor to facilitate oxygenation. In some cases, the mixture is cycled through the reactor more than once. Horizontal reactors are force-aerated drums, fed continuously or intermittently with mixture. The mixture is thoroughly agitated with constant rotation of the drum. Inclined reactors are binstructures which are continuously or intermittently fed with mixture. In most cases, both forced aeration and mechanical agitation of the mixture is simultaneously, employed.

3. Windrow composting

Compost is placed in long piles known as windrows and periodically mixed with means of mobile equipment. Moisture, pH, temperature and contaminant concentrations are monitored. At the completion of the composting period, the windrows are disassembled and the compost is taken to the final disposal area. Windrow compositing is usually considered to be the most cost-effective composting alternative.

Vermin composting

The use of compost can contribute to the maintenance and improvement of soil fertility. Composting is a method of organic fertilization used in agriculture and gardening. Worm compost (also known as vermin compost, from "vermin", the Latin for "worm") is an especially high-grade and nutrient-rich fertilizer. Many tea and coffee growers keep small herds of cattle for extra income and use the dung produced as feed substrate for worm composting. The nutrient-rich worm compost is then used as fertilizer on the tea and coffee plantations, and increases in harvest yields. Vermin culture can be practiced even on a small scale, and easily be integrated into any agricultural system. For example, the waste from the crops currently being produced and processed (e. g. coffee pulp, or cuttings from shade trees in tea gardens). Vegetable waste has a more complex structure and a higher C/N ratio than cattle slurry. Besides this, micro-organisms can pre-digest it, thereby ensuring good aeration. Worm humus is a fertilizer suitable for all types of crops.

The humus can be harvested within as little as 2 – 5 months after start-up. However, the conversion period and the worms' rate of reproduction always depend on the source material used, the worms' living conditions (humidity, temperature) and how well the composting is managed.

Worm compost is one of the highest-grade and most nutrient-rich natural fertilisers in the world. Its soil conditioning properties and plant-strengthening effect encourage the growth and yield of the plants.

Characteristics

- similar to the soil found in deciduous woodlands and mixed forests

- black, odourless and crumbly substrate

- balanced nutritional composition for plants

- it contains an above-average number of micro-organisms which revitalise the soil.

- loose yet stable soil structure (clay-humus complexes)

- absolutely free from all types of synthetic chemical additives

Conversion processes

- Accelerated conversion of organic waste matter by micro-organisms (bacteria, fungi) and by compost worms

- The worms coat the organic material with their mucous excretions which contain micro-organisms (bacteria, fungi etc.) --> microbial predecomposition

- The worms convert the pre-fermented composting material into worm humus, along with mineral substances

- Worm humus is high in micro-organisms, enzymes and nutrients --> ideal supplier of nutrients bonded in clay-humus complexes, good plant availability

- Cold composting (at temperatures below 50°C)

Plant nutritionists' encouragement of soil fertility

- Worm humus acts as an "appetiser" for plants, increasing their capacity to absorb water and nutrients

- Earthworm humus contains the essential nutrients of nitrogen (N), phosphor (P) and potash (K) in much larger quantities than are present in the soil or in comparable compost. This makes it richer than mature manure or garden compost

- During the course of composting, the ratio shifts in favour of N

(The C/N ratio of mature compost should be below 20. The higher the proportion of nitrogen in compost (primarily organically bonded nitrate and ammonium, the better, this complex process is performed by the worm in its gastrointestinal tract.)

Minimisation of solid waste with low toxicity and containing heavy metals

The worms are capable of processing of waste. This means they can be used to detoxify soils contaminated with solid waste, pesticides or heavy metals from industrial or agricultural waste. Worm enzymes and microbes in the worm humus can also degrade toxic substances. The toxicity level of worms should not be too high. To avoid these accumulated pollutants being passed on, the worm should be removed from the system. when the "contaminated" worm dies, everything will be go back into the soil. If the worm is used as a source of protein rich fodder, then the heavy metals will accumulate in the food chain.

Eisenia fetida

The most frequently used species of compost worm is the red wiggler (Eisenia fetida), which is naturally predisposed towards high rates of conversion and reproduction. it (grow to a length of 6 – 13 cm on average. They are reddish in colour, with yellowish rings. In threatening situations they exude a foul-smelling mucous, which is the reason for the name of this species: "fetida" means stinky.

Transformation of the organic material:

- Between half and the whole of the equivalent of its body mass a day (depending on conditions: climate, food supply)

- Under perfect conditions: 3,500 worms (approx. 1 kg) devour 1 kg kitchen waste a day

- 200 - 300 worms can convert a volume of 1 m² and 20 cm depth into worm humus within 60 days

- Of 100% source material, 15% is what remains in the form of worm compost

Feed

Compost worms, which have a huge appetite, feed on almost anything from vegetable or animal sources. However, Eisenia fetida is particularly partial to cattle excrement. Therefor, cattle manure is the most commonly used source material for worm composting. However, green and nutrient-rich vegetable waste is also composted. Generally speaking, a wide range of source materials is suitable as worm fodder. However, the waste used should be from organic agricultural sources. it is said that, the finer the material offered to worms the faster its conversion. The compost should remain fairly constant throughout the composting period.

Source material for the fodder

- Animal excrement from
1. cattle
2. horses
3. sheep
4. pigs
5. poultry
6. goats
7. hares
8. donkeys
- Vegetable waste
1. hay
2. grass
3. weeds
4. leaves
5. foliage, for example from tea or coffee trees (chopped small)
6. cereals
7. coffee pulp
8. bean pods
9. banana and orange peelings
10. forest soil, ash

Nutritional balance in feed

The nitrogen content should not be too high. The worms then try to escape, and those which are not fast enough die. Fresh cattle manure must be pre-fermented. It must be moistened in a separate bed, built on a slight slope. If 2 – 3 drops appear when it is squeezed, the manure can be added to the worm bed.

Feeding process

- At regular intervals of 10 – 30 days

- Manually or automatically

Various worm composting methods

Most worm composting methods are relatively simple and require little effort.

There are various methods:-

tray stacks, windrows, compost heaps and bins, complete recycling systems, containers and box systems. Sometimes a simple wooden chest is suffi-cient.

Size of the worm compost heap

Most compost heaps are 1 – 2 m wide, 30 – 50 cm high, and can be as long as desired. Since Eisenia fetida is an epigeic species, i. e. a surface dweller which works in the upper layers of the soil, the compost should not be over 60 cm deep.

Location of worm compost heaps

The compost heaps can be distributed between rows of trees, or housed in shelters.

Climate

The Eisenia fetida can tolerate temperatures between 0 - 30°C and is therefore well suited to locations in the open air. To ensure that the earthworm bed does not get too hot, shade trees or a roof should protect it from direct sunshine. Fresh manure must first be prefermented. The humus should not be too moist as it can otherwise lead to an infection of the female reproduction organs. (Test by squeezing it. No more than 5 drops of liquid should come out of a handful.) In order to obtain constantly high rates of yield and reproduction, the following general conditions should be maintained by making adjustments to the processes:

- Temperature 20°C - 25°C (ideally)

- Humidity 80%

- Sufficient oxygen (loose soil, to guarantee aerobic conditions)

- pH-value 7.5 – 8.0 (ideal), 5.0 - 8.4 (tolerance value) --> Acidic pH-value can be compensated by adding calcium carbonate

Construction of a worm farm

Stage 1: Bedding

To create a perfect climate, a "worm bed" is made by using coarse materials such as shredded twigs, coconut fibre, mulch or wood shavings/sawdust as a basis, varying ac-cording to what is available locally. All the components should have been produced organically.

Properties of the worm bed:

- Protection from extreme fluctuations in temperature

- Guarantees well-balanced humidity and aeration

Stage 2: Feed

The next step is to cover the worm bed with a layer of feed matter consisting of vegetable waste and manure.

Stage 3: Introducing the worms

The worms are added to the compost heap in batches.

Stage 4: Watering the worm compost

The amount of water needed depends on the climate (temperature, evaporation).

Stage 5: Cover the compost heap

In order to protect the worm population from predators such as birds, rats, snakes, cockroaches and ants, but also from heavy rains, the compost heap needs to be covered. Here, the most suitable materials are:

- Banana leaves

- Polyethylene foil

- Wood

- Bamboo

- Bbricks

- Corrugated sheeting

- Palm leaves

Stage 6: Monitoring the worm compost

The compost heap should be checked once a week

Harvesting the vermin compost

The compost can be harvested in about 2 – 5 months.

There are various ways to go about it:

If the compost heap takes the form of a windrow, the source material is introduced to one end of the windrow and added to continuously. Care should be taken that the new material added is in contact with the old substrate. The compost worms move over to the fresh substrate and continue conversion there. The older material can then be harvested and, if necessary, left to mature.

If the worm bed is constructed in layers, this should consist of several trays. The bottom tray (collecting pan) serves as a reservoir for the liquid seepage. The bottom of the working trays designed to hold the compost material should have holes or slits in them large enough for the worms to pass through. They are placed on the collecting pan. The first working tray is now

filled with the source material: at the bottom comes a layer of coarse material (e. g. wood shavings), and on top of this a layer of finer material (leaves and manure). As soon as most of the material has been converted to compost, the next working tray is placed on top of it, so that the bottom of this tray is in contact with the material below, and filled with fresh material. Once the worms have migrated up into the new tray, the worm compost can be removed from the lower tray. If the compost bed is on a slight incline and not filled completely, then the finished compost is sieved into the upper part. Alternatively, the upper humus layer can be removed carefully by hand, and the worms then retreat downwards.

In most cases the farms and co-operatives use the worm compost for their own fields and gardens, but there are plants which sell the worm humus

Storage of vermin compost

The worm humus is slightly moistened and then stored in sacks in the shade. The humus is stored for up to one month before being applied to the soil.

vermin wash

The seepage (vermiwash) drained from the worm bed is especially valued, and is used in diluted form as foliar spray. This concentrated liquid fertiliser contains valuable amino and silicic acids.

A method to prepare vermin wash

If vermin compost, when finished, is diluted with water, this becomes the liquid "vermin wash" ("humus liquido"). A decoction is made of one part vermin compost to ten or twenty parts water, and left to stand for between 15 and 24 hours. There are then two procedures to choose from: either an air pump is used to pump air into the concoction throughout this period, or no air is pumped in (a method which, however, since anaerobic, is suspected of producing substances harmful to plants).

Application of vermin wash

The vermiwash is either poured onto the soil or sprayed on the leaves. This strengthens the epidermis of the leaves and reduces damage by aphids and penetrating fungal spores. It is also possible to use vermiwash in drip irrigation or other standard methods of irrigation, as it reducing the amount of work required.

Vermin culture is more sensitive than other composting methods

- Vermicompost is susceptible to extreme weather conditions such as frost, heavy rainfall, drought and overheating.

- Anaerobic conditions (due to compaction) can lead to lack of oxygen.

- Every stage, from construction to feeding and irrigation, must be controlled and monitored.

Module 7. Effluent treatment and disposal

Lesson 10. Parameters of effluent like temperature, pH, Oxygen demands (BOD,COD), fat oil and grease content, metal content, forms of phosphorous and sulphur in effluent

Parameters of effluent

Temperature

It affects the activity of bacteria present in the waste water along with solubility of various gases in it. Further, based upon solubility, it may affect viscosity of sewage thus having an impact on sedimentation part of waste water. On an average of 20°C temperature is observed for waste water suitable from microbial activity point of view. However, when temperature is more, the D.O. content of waste water is reduced considerably.

pH

pH value of a solution may indicates negative log of hydrogen ion concentration present in waste water.

Mathematically, it can be expressed as:

$$pH = -\log_{10} H^+$$

$$H^+ = 10^{-pH}$$

Thus it indicates alkalinity/acidity of sewage

pH > 7 → Basic solution

pH = 7 → Neutral solution

pH < 7 → Acidic solution

The determination of ph of waste water helps us to choose suitable mode of treatment as suitability of treatment or to be more precise, efficiency of treatment depends upon ph value. So, it is very important parameter for waste water treatment. The ph of fresh sewage is generally falls because of production of acids by bacterial actions. It has been observed that with the passage of time, once sewage gets stabilized, ph starts increasing.

Presence of Fats, Oils and Grease

Fats, oils and grease may find its origin in waste water by discharges of animal/vegetable matter, or from the kitchens, hotels or restaurants, garages, milk plants, industries etc. This type of materials form scum on the top of sedimentation tanks and clog the pores of various filters. So, it need to be properly detected and checked at source before the waste water is being fed into treatment plant for sedimentation. To measure the quantity of fats and oils, a sample of sewage is evaporated. The residual solids left are then mixed with ether. The solution is then poured off and again evaporated. The residual left now behind will be fats and greases and thus can be easily removed by means of grit chambers or detritions tanks.

Oxygen demands

The availability of oxygen in water or waste water is very important. If the waste water has to be directly discharged into a water body/river, it should be able to provide dissolved oxygen of a minimum of 4 mg/l. The dissolved oxygen test performed on sewage prior to its treatment helps us to decide mode as well as degree of treatment. Moreover, it will let us know about the state of sewage means whether it is fresh or stale. Its only fresh sewage that contains a little of dissolved oxygen. It can be determined by Winkler's method. Two types of oxygen demands for waste water has to be determined that is BOD and COD.

BOD

It is Bio-Chemical Oxygen Demand. The waste water contains two types of matter. One that can be easily oxidized by the bacteria and thus called biologically active or degradable matter. The other part of material present in waste water cannot be degraded biologically and thus known as biologically inactive. BOD of sewage gives us the amount of biologically active organic matter present in sewage and is one of the most important tests of waste water as treatment processes/methodology that need to be adopted to it is based upon this value.

If good amount of oxygen is present in water then the aerobic biological decomposition of waste water will take place until the oxidation process is completed. The amount of oxygen consumed in this process is nothing but BOD. The bacteria present in sewage will keep on absorbing oxygen and the process of decomposition will keep on going for a number of months. It is practically not feasible to determine ultimate oxygen demand. So, BOD of water or waste water during 5 days at 20°C is generally taken as standard demand. It is about 68 % of the total demand. The standard BOD 5 day demand is designated as BOD_5 and is found in laboratory by diluting a known volume of a sample of waste water with a known volume of aerated pure water (dilution water) and then finding D.O. of this diluted sample. The diluted sample is then incubated for 5 days at 20°C. The dissolved oxygen of the diluted sample after 5 days is again calculated. This difference will indicate the O_2 consumed by sewage sample in 5 days. BOD_5 is thus calculated as

$$BOD_5 = \text{DO consumed by diluted sample} \times \left[\frac{\text{Volume of diluted sample}}{\text{Volume of undiluted sewage sample}}\right]$$

The factor in the right hand side in the above equation is nothing but dilution factor.

The rate at which BOD is deoxygenated depends upon amount and nature of organic material present in the sample and also on temperature of waste water.

Mathematically,

$$Y_t = L\left[1 - 10^{-K_D t}\right]$$
$Y_t = $ Oxygen absorbed in t days
$t = $ time (days)
$K_D = $ deoxygenated constant
$L = $ Organic matter present at start of BOD reaction

COD

The amount of oxygen required to decompose both biologically active matter and biologically inactive matter is known as chemical oxygen demand or COD. It can be calculated in laboratory by performing tests in a number of ways. The most commonly used is by using a strong oxidant like potassium dichromate $K_2Cr_2O_7$ or $KMnO_4$ to stabilize the organic matter to determine the molecular oxygen from the oxidant solution in oxidizing the organic matter present in the given waste water.

Metal Content

Waste water treatment systems for metals are pretty well defined for precipitation systems. The incoming solution is ph adjusted to the optimum range for precipitating metal as a hydroxide. In difficult situation a sulfide is added to increase recovery. The treated water is run through a clarifier to settle solids.

The standard heavy metal waste water treatment system adopts hydroxide precipitation for heavy metal removal. It may be aided with or without addition of sulfides. The sulfides results in a lower solubility than hydroxide precipitation alone.

Phosphorous

Municipal waste waters may contain 5-20 mg/l of phosphorous. Out of this 20-25% is organic and rest is inorganic. The usual forms of phosphorous found in aqueous solutions include:

- Orthophosphates: Available for biological metabolism without further break down.

- Polyphosphates: Molecules with 2 or more phosphate atoms, O_2 and some cases H_2 atoms combine to form complex substances.

Polyphosphates may get hydrolyzed and transform into orthophosphates; but this process is very slow. Phosphates can be removed by means of phosphate precipitation by addition of coagulant. The multivalent ions commonly used are Ca, Al and Fe. Normally secondary treatment systems can remove only 1-2 mg/l of phosphorous. Thus a large excess of phosphorous is discharged in final residues causing eutrophication in surface waters. New legislation require a maximum concentration of P discharges into sensitive waters of 2 mg/l.

Sulphur

It may be present in the form of sulphides, sulphates and H_2S in waste water. The determination of sulphur in these forms is rarely done however their presence may indicate aerobic and /or anaerobic decomposition. Sulphides and sulphates may be formed due to decomposition of various sulphur containing substances present in sewage; resulting in production of H_2S ($\uparrow$) and thus a very foul smell and odour. It may also cause corrosion of sewer pipes through it is carried away. If H_2S quantity in waste water is less than 1 ppm, it is hardly felt. Moreover sulphides and H_2S indicate initial stages of decomposition. Once the decomposition is over, only end products in form of sulphates are available which are comparatively stable and unobjectionable.

Lesson 11. Treatment of effluent, steps for waste water treatment, sedimentation, coagulation, flocculation and floatation

Whenever agricultural produce in any form, is handled, processed, packaged and stored, waste water is always generated. The waste water is much polluted and is to be treated depending upon its degree of pollution. It may be only preliminary treatment or preliminary treatment followed by primary treatment or further carried on to secondary treatment or even a complete treatment which include preliminary, secondary and tertiary treatment. The cost for treating waste water lies in its specific characteristics and standards for discharging either into water bodies or municipal waste water treatment plant.

Physical forces as well as chemical and biological processes drive the treatment of wastewater. Treatment methods that rely on physical forces are called unit operations. These include screening, sedimentation, filtration, or flotation. Treatment methods based on chemical and biological processes are called unit processes. Chemical unit processes include disinfection, adsorption, or precipitation. Biological unit processes involve microbial activity, which is responsible for organic matter degradation and removal of nutrients.

Waste water treatment comprises the following four steps:

1. **Preliminary treatment:** The objective of this operation is to remove debris and coarse materials that may clog equipment in the plant.

2. **Primary treatment:** Treatment is brought about by physical processe (unit operations) such as screening and sedimentation.

3. **Secondary treatment:** Biological (e.g. activated sludge, trickling filter, oxidation ponds) and chemical (e.g. disinfection) unit processes are used to treat wastewater. Nutrient removal also generally occurs during secondary treatment of wastewater.

4. **Tertiary or advanced treatment:** Unit operations and chemical unit processes are used to further remove BOD, nutrients, pathogens and parasites and sometimes toxic substances.

Preliminary Treatment

It consists mainly in separating floating materials, heavy settleable inorganic solids, rags, pieces of wood, oil and greases etc. These coarse material may clog the equipment of plant. The total removal of these materials may reduce the BOD by 15 to 25%. Different operations such as screening, grit chamber/detritious tank, skimming tank may be required for removing these products. The screens used could be vibrating, rotary or static type. Usually screens used have from 10mm down to 1mm opening materials of small size can be removed by high speed circular vibrating polishing screens. Screening systems may be used in combination to maximize the efficiency of the process. The efficiencies of these systems are variable. Rotary drum and discs shows removal percentage of suspended solids upto 40-50%.

Primary treatment

Primary treatment of waste water is done to remove large suspended organic solids. It can be done by sedimentation or screening. Sometimes preliminary treatment is also taken as part of primary treatment. It can be aided by sedimentation tank, coagulation tank and flocculation etc. It allows for the 30% and 60% removal of COD and total suspended solids respectively.

Sedimentation tank

The sedimentation process is mainly based on the concept of that organic matter present in waste water is having specific gravity greater than one. When waste water is made to store for hours, these material will settle down. This is the principle behind sedimentation and accordingly settling velocity is decided; being governed by Stoke's law

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{v} \quad \text{for } d < 0.1 \text{ mm}$$

It is applicable for viscous flow and small sized particles, represented by Reynold No. < 0.5

V_S = Velocity of settlement of particle in m/sec

d = diameter of particle in meter

υ = Kinematic viscosity of water

G = Specific gravity of particle

Sedimentation tanks have been used to treat waste water for millennia. Sedimentation is often used in the primary stage in modern waste water treatment plant, reducing the content of suspended solids as well as the pollutant embedded in the suspended solids. Due to the large amount of reagent necessary to treat domestic waste water, preliminary chemical coagulation and flocculation are generally not used, remaining suspended solids being reduced by following stages of the system. However, coagulation and flocculation can be used for building a compact treatment plant (also called a "package treatment plant"), or for further polishing of the treated water.

In Acivated Sludge Treatment process, flocs being created through biological activity are collected in sedimentation tanks, generally referred to as Secondary Clarifiers or Secondary Sedimentation Tanks. Sedimentation tanks can be different shapes, often rectangular or circular. They are sized in order to have an optimal sedimentation speed. If the sedimentation speed is too high, most particles will not have sufficient time to settle, and will be carried with the treated water. If the speed is too low, the tanks will be of an excessive size. As turbulence is a damaging factor leading settled particles to go back in suspension, several devices are used to ensure a quiet flow, such as carefully designed water inlet with baffles.

Sedimentation may be made efficient by the use of stacks of flat pieces that slope slightly upwards in the direction of flow, called lamellar separators. They are parallel and separated by a small distance. These structures work in two ways:

1. They provide a very large surface area onto which particles may fall and become stabilized.

2. Because flow is temporarily accelerated between the plates and then immediately slows down, this helps to aggregate very fine particles that can settle as the flow exits the plates.

The use of lamellar separators may allow the use of a smaller sedimentation tank and may enable finer particles to be separated. Typically such structures are used for difficult-to-treat waters, especially those containing colloidal materials.

Features of sedimentation design

Inlets to a settling tank are designed to dissipate the inlet velocity, to distribute the flow uniformly, and to prevent short circuiting. The inlet and outlet channels are designed for a minimum velocity of 2 feet per second at the average flow rate and will have corners filleted to prevent deposition and collection of solids. The following table shows the dimensions of rectangular and circular tanks.

Clarifier length or diameter, ft	Minimum liquid depth, ft	Sludge blanket depth, ft	Minimum total depth, ft
Rectangular upto 50 ft length	6	2	8
50 – 100	6-7	2	8-9
100 – 150	7-8	3	10-11
150 – 200	8-9	4	12-13
Circular upto 50 ft diameter	7	2	9
50 – 100	7-8	2	9
100 – 150	8-9	3	11-12
150 – 200	9-10	4	13-14

Rectangular tanks

The minimum length of flow from inlet to outlet of a rectangular tank is 10 feet in order to prevent short circuiting of flow in the tank. In existing installations, tank length-to-width ratio varies between 3:1 to 5:1. Tanks are designed with a minimum depth of 7 feet except final tanks in activated sludge plants, which are designed with a 9 foot minimum depth.

Inlets and outlets

Inlets to rectangular tanks are designed to prevent channelling of waste water in the tank. Submerged ports, uniformly spaced in the inlet channel, are an effective means of securing distribution without deposition or channelling. Outlet overflow weirs used in rectangular tanks are of the adjustable type, and serrated weirs are preferred over straight ones. Overflow weirs are used in most cases.

Collection and removal of scum and sludge

Means for the collection and removal of scum and sludge are required for all settling tanks. The removal of scum from the tank take place immediately ahead of the outlet weirs, and the equipment may be automatic or manual in operation. Provisions are made so that the scum may be discharged to a separate well or sump so that it can be either sent to the digester or disposed of separately. Rectangular tanks will be provided with scum troughs with the crest about 1 inch above maximum water surface elevation. For small installation (less than 1.0 million gallons per day), hand-tilt troughs consisting of a horizontal, slotted pipe that can be rotated by a lever or screw can be used. Proven mechanical scum removal devices such as chain-and-flight types may be used for larger installation. To minimize the accumulation of sludge film on the sides of the sludge hoppers, a side slope of at least 1.5 vertical to 1 horizontal is used. Separate sludge wells, into which sludge is deposited from the sludge hoppers and from which the sludge is pumped, are preferable to direct pump connections with the hoppers.

Secondary sedimentation

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.
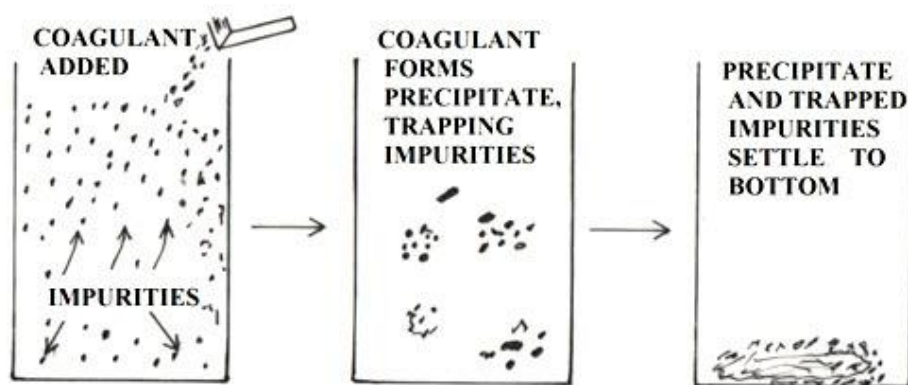
Flocculation

Flocculation, in the field of chemistry, is a process wherein colloids come out of suspension in the form of floc or flakes by the addition of a clarifying agent. The action differs from precipitation in that, prior to flocculation, colloids are merely suspended in a liquid and not actually dissolved in a solution. In the flocculated system, there is no formation of a cake, since all the flocs are in the suspension.
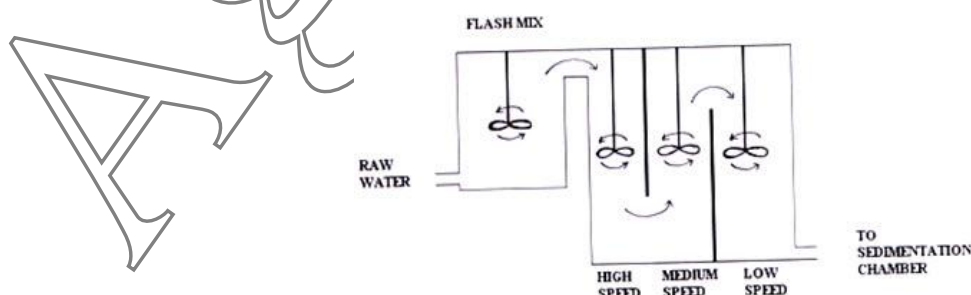
In theory and at the chemical level, coagulation and flocculation is a three step process, consisting of flash mixing, coagulation and flocculation. However, in practice in the treatment plant, there are only two steps in the coagulation/flocculation process – the water first flows into the flash mix chamber, and then enters the flocculation basin.

In the **flash mixer,** coagulant chemicals are added to the water and the water is mixed quickly and violently. The purpose of this step is to evenly distribute the chemicals through the water. Flash mixing typically lasts a minute or less. If the water is mixed for less than thirty seconds, then the chemicals will not be properly mixed into the water. However, if the water is mixed for more than sixty seconds, then the mixer blades will shear the newly forming floc back into small particles.

After flash mixing, coagulation occurs. During coagulation, the coagulant chemicals neutralize the electrical charges of the fine particles in the water, allowing the particles to come closer together and form large clumps.

The final step is **flocculation.** During flocculation, a process of gentle mixing brings the fine particles formed by coagulation into contact with each other. Flocculation typically lasts for about thirty to forty-five minutes. The flocculation basin often has a number of compartments with decreasing mixing speeds as the water advances through the basin. This compartmentalized chamber allows increasingly large floc to form without being broken apart by the mixing blades.

Floc

The end product of a well-regulated coagulation/flocculation process is water in which the majority of the turbidity has been collected into floc, clumps of bacteria and particulate impurities that have come together and formed a cluster. The floc will then settle out in the sedimentation basin, with remaining floc being removed in the filter. The best floc size is 0.1 to 3 mm. Larger floc does not settle as well and is more subject to breakup in the flocculation basin. Smaller floc also may not settle.

Flotation

Floatation aims at the removal of fine suspended particles whose separation by sedimentation is practically infeasible as it would require very long treatment times. In general, particles with specific gravity less than unity tend to float spontaneously (e.g., as in the case of skimming); on the other hand, floatation of particles that are only marginally heavier than water can be assisted by introducing fine air bubbles in the liquid. In this case, the bubbles

attach to the particulate matter and the buoyant force of the combined particle and gas bubbles is great enough to bring the particle to the surface.

There are three distinct methods to introduce the gas into the liquid as follows:

1. **Dissolved air floatation:** Air is dissolved in the liquid under a pressure of several atmospheres which is released and the air is then liberated in the form of fine bubbles 40-70 micrometers. This is the most common method used in wastewater treatment.

2. **Air floatation:** In this case, air is introduced directly to the liquid through diffusers or revolving impellers.

3. **Vacuum flotation:** It consists of saturating the liquid with air followed by the application of partial vacuum which causes the dissolved air to come out of the solution as fine bubbles.

4. **Electrolytic floatation:** It is based on the formation of oxygen and hydrogen bubbles from water electrolysis.

Regardless of how air is dissolved in the liquid phase, removal efficiency can be enhanced with the addition of various chemicals such as aluminum and iron salts. These tend to increase and/or alter the particle surface, thus facilitating bubble attachment.

Lesson 12. Characteristics of food processing waste water, trickling filters, rotating biological contractors

BOD and COD are common measurements to determine water quality. They measure the strength of waste stream by measuring the O_2 required to stabilize the wastes. As these substances degrade they consume dissolved O_2 in water. The amount of O_2 used is thus a good indicator of their amount of organic waste present. BOD and COD are important in food processing industry because they can be used to indicate lost products and wasteful practices. High BOD and COD levels indicate increased amounts of product lost to the waste streams. COD values are always greater than BOD values because of the nature of the measurement procedure. With the dichromate refluxing procedure used to measure COD almost all organic compounds are oxidized. However, with BOD procedure, some of these compounds do not fully oxidize making oxygen demand lower.

Characteristics of Food processing waste water

| Parameters	COD(mg/l)	BOD(mg/l)
Dairy	900-7000	500-5000
Olive oil mill	20400-77200	-
Winery	7130-27200	600-1400
Vegetables	250-15000	125-4700
Cheese	1000-7500	588-5000
Mixed dairy processing waste waters	1150-9200	4700
Bakery products	3200	7000
Jams and jellies	2400	4000
Meat packing	1433	2746
Meat specialities	530	900
Poultry process	1306	1581
whey	32000	70000

The trickling filter

The trickling filters are also called percolating filters. The trickling filters are similar to contact beds in construction but allows constant aeration and the action is continues. The main function of the trickling filter is to remove unstable, organic materials in the form of dissolved and finely divided organic solids, and to oxidize these solids biologically to form more stable materials. In the trickling filter no sludge is returned to the incoming waste water. Rather the waste water is sprayed uniformly by a rotating distributor on a bed of rocks 6-10 ft deep. The

rotation may be powered by an electric motor or a hydraulic impulse. The water percolates over the rocks within the bed which are 1-4 in diameter and is collected in an under-drain. The liquid is then collected from the under drain and allowed in a sedimentation tank which is an integral component of the trickling filter. The sludge from the sedimentation tank is removed from time to time. Various modifications of this basic system exist. In one modification the water may be pre-sedimented before introduction to the filter. Two filters may be placed in series and the effluent may be recycled. A coating of microorganisms form on the stones as the waste water trickles down the filter and these organisms break-down the waste. Fungi, algae, protozoa and bacteria form a thin film called zoogleal slims on the rocks. As the filter ages the aerobic bacteria which are responsible for the breakdown of the organic matter become impeded, the system becomes inefficient and flies and obnoxious smells may result. The microbial coating sloughs off from time to time. As the biota unable to cling to the film die, they are discharged from the filter with more or less partially decomposed organic matter. This is called 'sloughing'. The sloughing of material may occur periodically as in a standard rate filter or continuously as in a high rate filter.

The essential features necessary to the process are:

1. Sufficient surface area must be provided for biological growth.

2. Free O must be available at the surface to replenish the dissolved O extracted from the liquid layer.

3. Industrial wastes must be amenable to biological treatment.
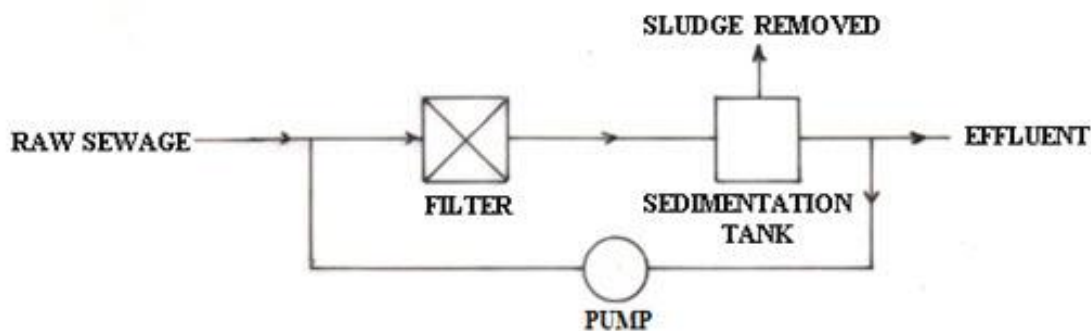
(a) Filtration without pre-sedimentation
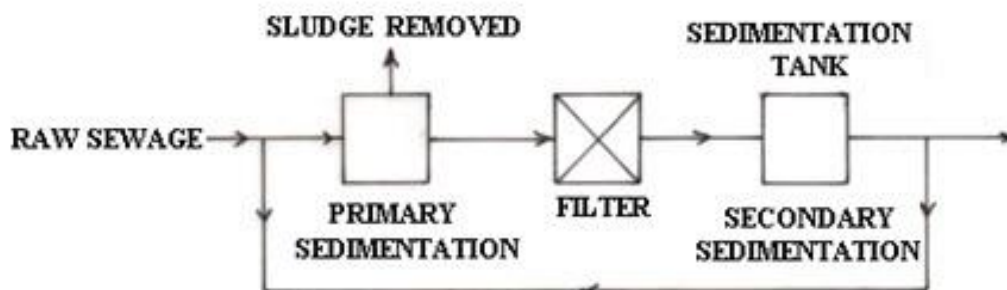
(b) Filtration with pre-sedimentation

Fig. 12.1 Arrangements of tickling filter

Advantages of trickling filters

1. They are self cleaning rate of filter loading is much higher.

2. No diminishing of capacity. Even if overdosed, they can recoup rest.

3. They are cheap and simple in operation.

4. Mechanical wear and tear is very small.

Disadvantages of trickling filter

1. High head loss through the filter making automatic dosing of filters as necessary.

2. Problem of odour and fly

3. Large land area is required. Cost of contraction is relatively higher.

4. They require preliminary treatment and therefore can not raw waste as such.

Rotating discs

Rotating discs are also known as rotating biological contractors. These consist of closely packed discs of PVC mounted on a horizontal shaft and patially (35-40%) submerged in waste water contained in a cylindrical tank made of steel or RCC. The discs are rotated slowly at 1-2 revolutions per minute by means of a driving mechanism. As the discs rotate out of water, aeration is achieved by exposure to atmosphere. As the waste water flows down through the discs, the submerged micro-organisms absorbs food and picks up a thin layer or 2 lime of waste water. With repeated action, a microbial film of 1-2 mm thickness develops. The disc rotation enables the slimy layer to slide down and mix with the substrate. This results in solids sloughing which is kept in suspension till its removal along with the effluent. The action is similar to the biological action taking in the trickling filter. Staging is the essential part of the RBC system. This requires compartmentalization of RBC discs to form a series of independent cells. Stages can be accomplished by using baffles in a single tank or by use of separate tank in series.
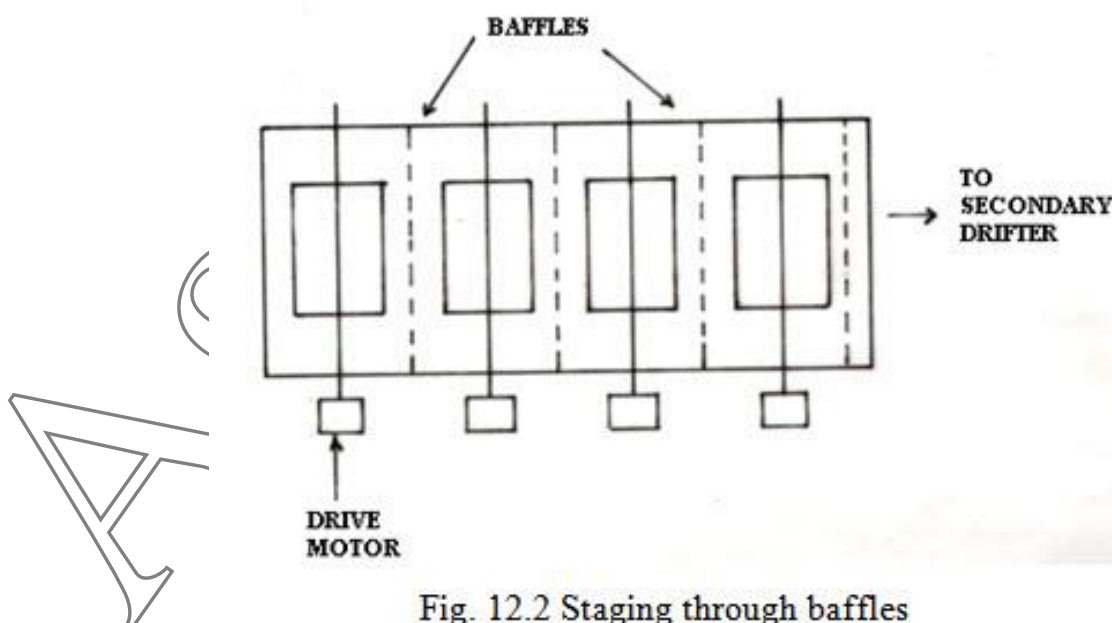

Fig. 12.2 Staging through baffles

Advantages of RBC

1. Compared to the trickling filter, the hydraulic and organic loading rates are much less for primary settled sewage though BOD removal efficiency could be as high as 90% for a detention period of 1-2hrs.

2. Simplicity of operation

3. Relatively low energy cost

Lesson 13. Oxidation ditches, activated sludge process, lagoons

Oxidation ditches (oxidation ponds) sludge process, rotating biological contractors and aerated lagoons are different types of secondary treatment of waste water. All these systems depend upon the growth of various microbes which degrade the organic matter present in the waste water. Therefore, also called as biological treatment.

Oxidation Pond

The basic biological phenomena in the treatment of waste in aqueous environment is as follows:

- The degradable organic compounds (carbohydrates, proteins and fats etc.) are broken down by aerobic microorganisms mainly by bacteria and to some extent by fungi. This results in an effluent production which is having very less organic matter.

- The materials which are very difficult to digest form a sludge, which is removed from time to time and can also be treated separately.

It is an artificial pond in which waste water can be retained for a sufficient time to satisfy the BOD (Biological Oxygen Demand) and make the waste non-putrescible. The purifying action of oxidation pond is due to unique relationship between algae and bacteria in shallow ponds.

Bacteria metabolize organic matter and releases nutrients like Nitrogen, Phosphorous and CO_2. Algae use these compounds along with energy from sunlight for synthesis of organic matter and releases O_2 into solution. O_2 released by algae is taken by bacteria, thus closing the cycle. This type of relation is called Symbiosis. It is common among living organisms in the pond. Besides these, other micro-organisms like protozoa, rotifers etc. also live in those waters and feed on algae and bacteria.

- Oxidation ponds act as facultative ponds because of shallow depth (< 2m). As the raw waste effluent without primary treatment enters the pond, the organic solid settles to the bottom and decompose anaerobically forming a sludge zone at the bottom and produce intermediate products. These products are acted upon by facultative and aerobic bacteria and converted into stabilized nutrient form. O_2 is added to the waste water in the pond by wind action at the surface and from day light metabolism of algae.

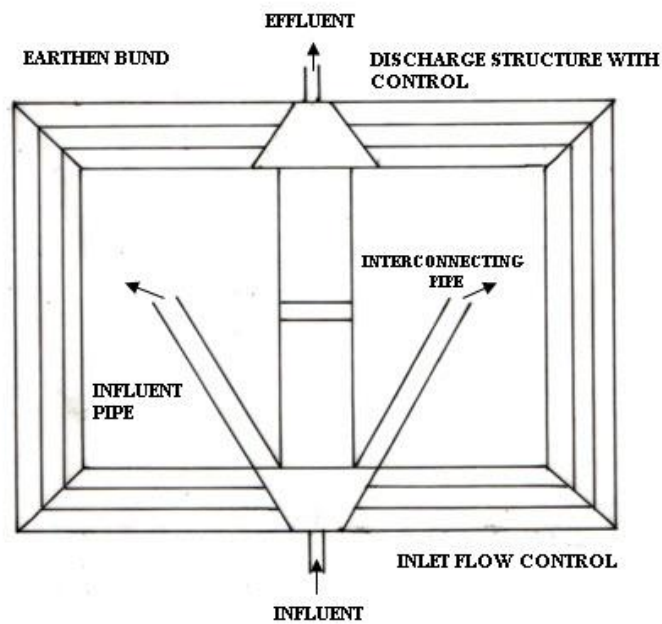- It is Highly efficient system as BOD removal is 90% and Coli form removal is > 99%

Fig. 13.1 Plan of oxidation pond

- Oxidation ponds are rectangular in shape (L/B = 2-3/1) having side slopes (1:1.5) and are constructed by building embankments of earth (Fig.13.1). They are of shallow depth usually 0.9-1.5m and as such effective in permitting penetration of sunlight to all parts of the waste water encouraging algal growth. Influents is applied in the middle of pond and allowed to be spread by the action of wind currents which prevents any odour nuisance due to concentration.

- Usually more than 1 in numbers are operated either in parallel or series.

- Operating ponds in series generally causes increased BOD reduction by preventing short-circuiting.

- Parallel operation is desirable to distribute the raw BOD load and avoid potential odor problems.

Oxidation ponds are suitable in case of small cities where large land areas are easily available and cheap. Also, in tropical countries where dry climate and warm temperature is prevalent

Advantages of oxidation ponds

- Low cost

- Quickness of construction

- Easy maintenance

- High efficiency of BOD removal

Disadvantages of oxidation ponds

- Nuisance due to mosquito breeding and odours.

Oxidation ditch

It is a modified form of activated sludge process (extended aeration type)

- It is highly efficient involving simple waste treatment

- Comparable in performance with the oxidation pond.

The process involves a single unit treatment in an endless channel equipped with a special type of rotor which serves the dual purpose of oxygenation and circulation.

- The ditch comprises of a trapezoidal cross-section of relatively shallow depth (0.9-1.5m) forming a continuous circuit.

- There is normally no primary tank and raw waste water passes directly through a bar screen to the ditch.

- Oxidation ditch forms the aeration basin where raw waste water is mixed with active organisms in ditch

- Cage rotor entrains the necessary O_2 into the liquid and keeps the contents of the ditch mixed and moving.
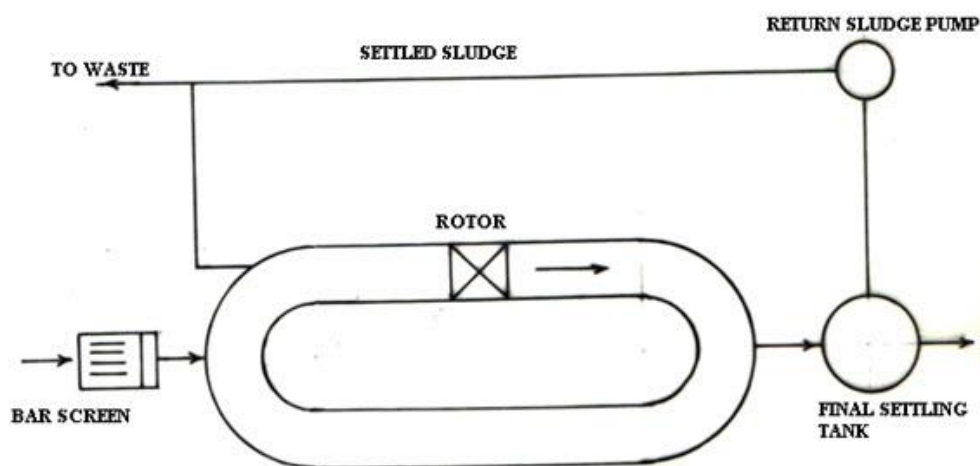

Fig. 13.2 Oxidation ditch process

- Physical cum biological process occurs where a small portion of the organic matter under goes direct chemical oxidation while bulk of organic matter is stabilized by biochemical activities of micro-organisms.

- The mixed liquor in the ditch flows to the clarifier for separation. The clarified liquid passes over the effluent well for disposal into receiving streams, while the settled sludge from the bottom of clarifier is removed by pumping and returned to the ditch for undergoing treatment.

- Detention period upto 24 hrs and is designed to carry mixed liquor suspended solid concentration of 3000-8000 mg/l with minimum circulation speed of 25 cm per second in the ditch.

- The plant can be operated continuously or intermittently.

- They can treat waste efficiently having BOD as high as 8000 mg/l

- This process has been used to treat domestic as well as industrial waste.

Activated sludge process

This is an aerobic breakdown of raw waste water. It is most widely used for treating waste water. Its main features are as follows:

a) It uses a complex population of micro-organisms (bacteria & protozoa)

b) This community of microorganisms has to cope with an uncontrollably diverse range of organic and inorganic compounds some of which may be toxic to the microbes.

c) The microbes occur in discreet aggregates known as flocs which are maintained in suspension in the aeration tank by

1. Mechanical agitation

2. Aeration

3. By mixing action of bubbles from submerged aeration systems.

Flocs consist of bacterial cells, extracellular polymeric substances and adsorbed organic matter. These are highly variable in morphology, typically 40-400 μm in size and are not easy to break apart.

d) The flocs must have good settling properties so that separation of biomass of microbes and liquid phases occurs efficiently and rapidly in the clarifier. Sometimes proper separation is not achieved giving rise to problems of bulking and foaming.

e) Some of the settled biomass is recycled as returned activated sludge or RAS to inoculate the incoming raw waste water because it contains a community of organisms adapted to the incoming waste water.

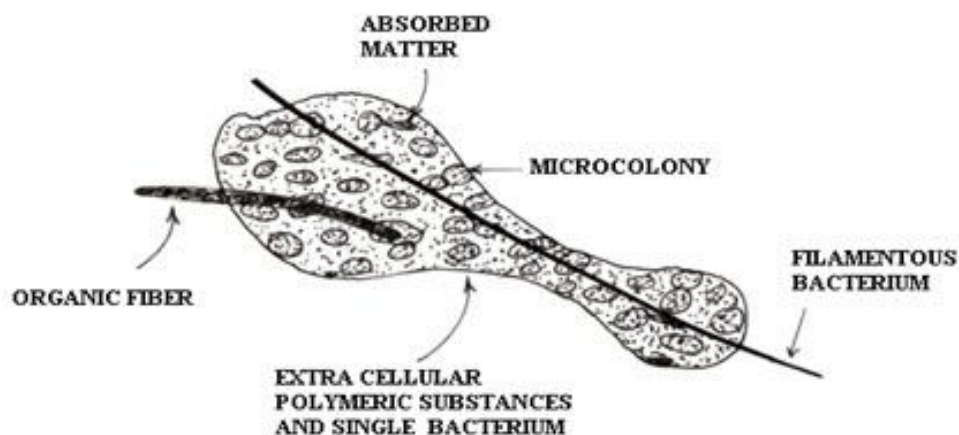f) The solid undigested sludge may be further treated into economically valuable products.

Fig.13.3 Diagram of a floc

Advantages of activated sludge process

- Efficiency

- Economy of space

- Versatility

Modifications of activated sludge setup:

1. Conventional activated sludge set up

The basic components of the conventional systems are aeration tank and a sedimentation tank. Before raw waste water enters the aeration tank, it is mixed with a portion of the sludge from the sedimentation tank. The content of raw water are therefore broken down by organisms already adapted to the environment of the aeration tank. The incoming organisms from the sludge exits in small flocs. It is the introduction of already adapted flocs of microbes that gave rise to the name activated sludge. Usually, 25-50% of the flow through the plant is drawn off from the sedimentation tank.

2. Tapered aeration

In this, aeration is heaviest at the point of entry of waste water and diminishes towards distal end. The reason behind this is that concentration of organic matter is heavy at entry point where mixture of raw waste and returned sludge enters the aeration tank. The diminishing aeration may be made directly into the main aeration tank or a series of tanks with diminishing aeration may be set up.

3. Step aeration

Here feed is introduced at several equally spaced points along with length of the tank thus creating more uniform demand in the tank. The aeration may be done in a series of tanks just like tapered aeration.

4. Contact stabilization

This is used when the waste water has a high proportion of colloidal material. The colloid rich waste water is allowed contact with sludge for a short period of 1- 1.5 hrs in a contact basin which is aerated. After settlement in a sludge separation tank, part of the sludge is removed and part is recycled into an aeration tank where it is mixed with the incoming waste water.

5. The pasveer ditch

This consists of a stadium shaped shallow (about 3") ditch in which continuous flow and oxygenation are provided by mechanical devices. It is essentially the conventional activated sludge system in which material is circulated in ditch rather than in pipes (Fig.13.4).
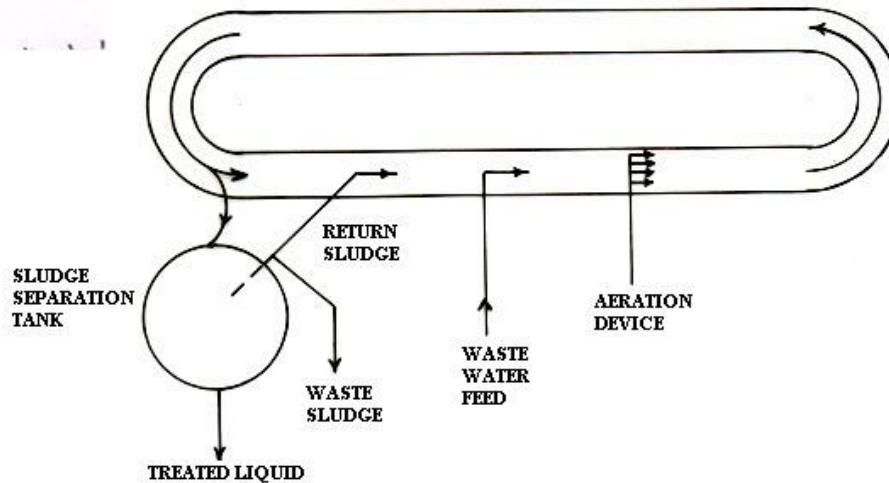
Fig.13.4 The pasveer ditch

6. The deep shaft process

This system is developed by Agricultural Division of Imperial Chemical Industries (ICI) UK. It consists of an outer steel lined concrete shaft measuring 300 ft or more and is installed into the ground. Waste water and sludge recycle are injected down a inner steel tube. Compressed air is injected at a position along the centre shaft deep enough to ensure that the hydrostatic weight of the water above the point of injection is high enough to force air bubbles downwards and prevent coming upwards. The demand air lower down the shaft providing O_2 for the aerobic breakdown of wastes. The water rises in the outer section of the shaft (Fig.13.5).
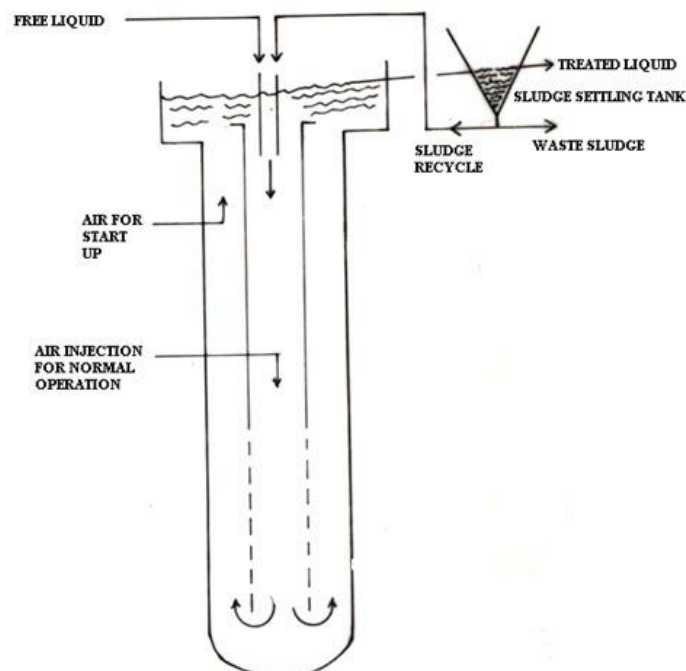

Fig.13.5 The deep shaft aeration system

Advantages of the deep shaft process

1. Greater rapidity in reducing BOD

2. 50% reduction in sludge

3. Space required is less

7. Enclosed tank systems and other compact system

Since breakdown of waste in aerobic biological treatment is brought about by aerobic microorganism, efficiency is increased by the use of O_2/oxygen enriched air. Enclosed tank in which the wastewater is completely mixed with the help of agitators, are used for aeration. Sludge from sedimentation tank is returned to the enclosed tank along with raw water.

Advantages

1. Absence (or greatly reduced) obnoxious smell from exhaust gases

2. Increased efficiency of waste stabilization.

This system is widely used in industries the world over.

Compact activated sludge system

This system does not have a separate sedimentation tank. Instead sludge separation and aerobic breakdown occurs in a single tank.
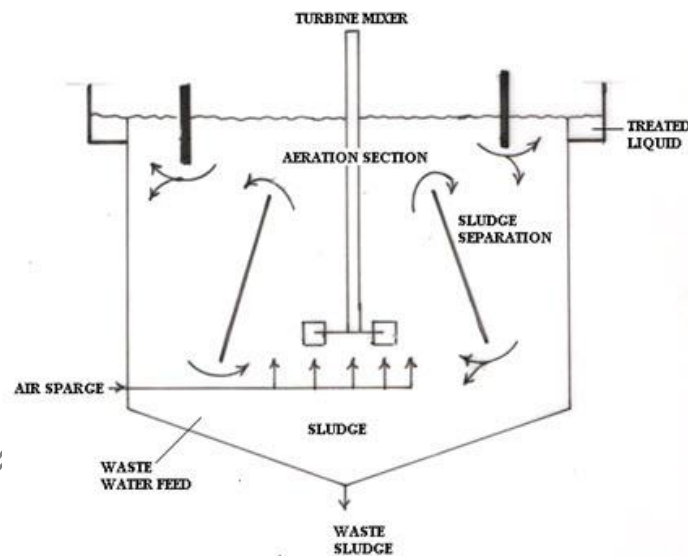
Fig.13.6 Compact activated sludge system

Advantage: Economy of space

Microbes involved in Activated Sludge Process (ASP)

Mainly bacteria and ciliates (Protozoa). *Zooglea ramigera* (slime forming), Pseudomonas, Achromobacter, Flavobacteria etc.

Efficiency of system is determined by reduction in BOD. In conventional activated sludge plants, the contact time is approximately 10 hrs, after which 90-95% BOD is removed. When contact time is less, BOD removal is 60-70% and sludge produced is more. With longer contact time, says several days, BOD reduction is over 99%.

Aerated lagoons

Aerated lagoons are also called suspended growth aerated lagoons. They are relatively shallow basins made in soil and are provided with mechanical aerators fixed on plateforms. These aerators provide O_2 for the biological treatment of waste water which ultimately stabilizes the organic matter.

Waste water after undergoing primary treatment through screens enters the lagoon and after biological pretreatment leaves from other side.

Lagoons are of two types

1. Facultative lagoons

2. Aerobic lagoons

Facultative lagoons

Here some solids settle down on the surface of the lagoon and rest may leave with effluent. The lower part of lagoon is anaerobic while upper is aerobic. So, these are called facultative.

Aerobic lagoons

These are the lagoons in which liquid is thoroughly aerated from the bottom so as to keep all solids in suspension.

- No settlement of solids occurs in such lagoons

- Solid concentration in effluent is very high, so further treatment is necessary.

Therefore, Facultative lagoons are most commonly used.

Advantages of lagoons

1. Simplicity in operation

2. Less machinery used

3. Low power consumption (0.75 w/cum lagoon volume)

Other Characteristics

- Depth of lagoons: 2-5m

- Period of detention: 2-5 days

- BOD removal efficiency: 90%

- Nitrification absent

- Sludge accumulation @ 0.04 cum/person/year

- Sludge removal once in 5 years: 95% and sludge extremely low.

Lesson 14. Filteration, slow sand filter, rapid sand filter, disinfection of water

Tertiary or advanced treatment pertains to the unit operations and chemical unit processes which are used to further remove BOD, nutrients, pathogens, parasites and sometimes toxic substances. These include both physical and chemical processes, like filteration using sand, coal or activated carbon filters or chemical oxidation processes which utilizes chlorination, H_2O_2 fentons reagent, ozone and permanganate.

The physical oxidation processes which include

- UV oxidation

- Sonication

- Wet air oxidation

- Supercritical water oxidation (SCWO)

Filteration

Filteration is defined as the process of allowing waste water to pass through a thick layer of sand or other filtering media. Filters may be classified as slow sand filters and rapid sand filters depending upon the rate of filteration. The phenomena of filteration is quite complex, but generally four function are performed.

1. **Mechanical straining:** which removes large suspended matterwhich cannot pass through interstics between sand grains.

2. **Sedimentation and adsorption:** accounts for the removal of colloids, suspended and bacterial particles. The interstices between sand grains act as minute sedimentation basins.

3. **Biological metabolism:** it is the growth and life process of the living cells. The surface layer gets coated with a zoogleal film in which bacterial activities are highest.

4. **Electrolyte action:** a certain amount of dissolved and suspended matter in H_2O is ionized which interacts with particles of sand which are also ionized. These neutralize each other and while doing so, change the chemical character of water.

The selected filter sand should be free from clay, loam, vegetable or organic matter. It should also be of uniform and of proper size. If the sand is too fine, it tends to quickly clog which causes a greater loss of head in the filter.

If the sand is too coarse, it will permit suspended solids and bacteria to pass through voids between the sand grains. Effective size of the sand is defined as the sieve size in mm which permits 10% of the sand by weight to pass or in other worlds, as the size of the grain that is larger than 10% by weight of all the particles comprising the sand.

Construction of slow sand filter

It consists of a water tank, 2.5-3.5m in depth, having a sand bed 0.6-0.9m thick, supported on a bed of gravel 0.3-0.45m thick laid in 5-6 layers, beneath with the under drainage system is laid over a concrete bed sloping towards a central longitudinal drain. The underground system consists of open-jointed drains of baked clay or concrete pipe in length of 30-40m which a maximum spacing of lateral of 2m.
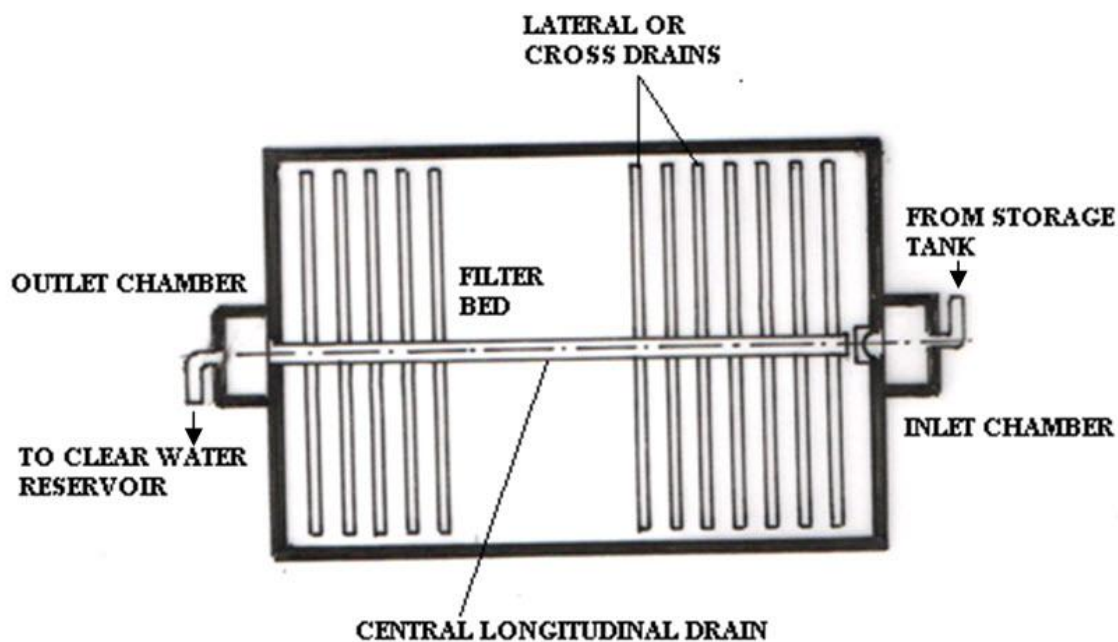
Fig. 14.1 Plan of slow sand filter

The raw mater is led gently on the filter bed, percolating downwards passes through the underdrains iinto an outlet chamber.

Construction of rapid sand filter (Gravity type)

It consist of an oper water-tight tank 3-3.5m deep of masonry or concrete with a concrete floor having coarse sand 0.6-0.75m thick, laid on the top with a layer of grated gravel 0.6-0.75m thick, laid on the top with a layer of grated gravel 0.45m thick supporting below. The gravel is underlain by an underdrainge system consisting of cast iron, central longitudinal conduct or manifold with strainers mounted on top and pipes of smaller diameter called lateral branching off at right angle to the manifold. The laterals are fixed 15-30cm centres and carry perforations on sides and bottom. About 1.75-2.5m of water depth may be allowed on the filter bed.

Comparative characteristics of slow sand filter and Rapid Sand filters

Characteristic	Slow Sand Filter	Rapid Sand Filter
Area	Require more area	Require less area
Size of sand or filtering media	Sand grains are finer. Effective size lies between 0.3-0.35mm Uniformly coefficient is 2.	Sand grains slightly coarser. Effective size lies between 0.45-0.70mm Uniformly coefficient is 1.70 maximum.
Rate of filteration	Low 100 to 200 litres/m²/hr.	High 2000 to 6000 litres/m²/hr.
Loss of head	It is very small. Only 0.6-0.9m	It is more -2.5 to 3m.
Supervision	Simple to operate. Does not require Skilled operators	Requires skilled operators.
Coagulation	Does not require premliminary coagulant mixing.	Requires the addition of a coagulant in order to get satisfactory filteration.
Method of cleaning	Washing is done by scrapping a thin layer of sand from the surface.	Washing is done by reversing the flow of water, taking the help of compressed air and a high pressure of wash water. Washing is completed in a few minutes, say 15-30 minutes.
Period of cleaning	Once every 2-3 months	24-48 hr
Amount of wash water	0.2-0.6% of filtered water.	2-4% of filtered water.

Efficiency	Remove bacteria completely because the rate of filteration is slow	Remove bacteria only partially. It is more efficient in the removal of colour. because the rate of filteration is slow
Operating Cost	Operating cost per thousand litres of water treated is less.	It is more
Maintenance cost	Small	More because of maintenance of pumps for pumping up wash-water and a compressor unit for obtaining compressed air.

Drawbacks of rapid sand fillers

Due to filetration on graded sand the majority of impurities are removed and stored in the limited space available in top sand layers. As the filters gets stratified after back washing it leads to surface clogging with quicker build up of head loss at higher velocity of filteration. Therefore the rapid sand filter has to be operated at somewhat lower filteration rates with shorter filter runs. The fine to coarse gradation of filter medium often results in poor filterate quality due to non-removal of finer-floc particles which may lodge in the region below the top sand layers.

To offset these drawbacks, indepth filteration is done where impurities laden water first passed through a medium having maximum pore space for arresting impurities. After this, the resulting water travels deeper into filter beds come in contact with the layers having smaller pore size. This enables the smaller sized particles to be detained and finally removed along with the finer floc particles.

This leads to higher quality filterates and greater utilization of the lower filter bed layers and consequently increased filter runs. This concept of indepth filteration uses the following filters:

1. Dual media filters

A dual media filter consists of a fine sand layer topped with a bed of anthraute coal each generally 30cm deep. The coarser an thracite top layer has intustices about 20% larger than the sand media. These openings are capable of adsorbing and trapping particles so that the flocs carried once in clarifier does not accumulate on the filter surface and sand bed forematurily. Because of the different specific gravity f the two materials (Coal 1.4 and sand 2.65), the coal of proper size in relation to the sand remains on top of sand during back washing.they have high rate of filteration of about 12000-15000 litres/m^2/h with the produce of high quality water. However, due to low total surface area of media particles they have a low resistance to turbidity break-through with changing flow rates.

2. Mixed media filter

A mixed media filter is a three layer filter of three properly graded materials: Coal (sp. gr.1.4), sand (sp.gr.2.65) and garnet (sp.gr.4.2) in the proporation of 60, 30 and 10% resp. the

particle sizes range from 1.0mm to 0.12mm from top to bottom of filter bed. After back washing, the three materials are mixed thoroughly through out the depth of the bed. However, at each level in the bed particles of coarse coal, medium sand and fine garnet are present.

Particles of turbidity in the influent to the mixed filter first pass through large pores and encounter the coarse media then reach smaller pores resulting from the mixing of finer media with coarser occur. Materials are removed and sorted throughout the full depth of the bed.

- The vast storage capacity of the mixed media filters greatly inceases the length of filter runs.

- The total surface area of the grains is much more resistant to break-through and more tolerant to increases in filter rates.

- It is thus possible to achieve filter rates of 1500litres/m²/hr.

Activated Carbon filters is based on liquid to solid adsorption process which remove a solute from water via a selective solid resin. Physical adsorption involves weak Vanderwaal's forces. Chemical adsorption involves stronger interactions (e.g ion excahange or hydrogen banding between the solid and the solute).The solids may be

- Activated carbon

- Activated alumina

- Organoclays etc.

Adsorption can occur in fluidized, move or fixed bed as wll as in upflow pressure or gravity contact systems (in which the adsorbant is dropped through a column of water). The fixed resin bed is typically used in waste water treatment, it involves passing waste water down through a paxked column of resin.

Activated carbon is the most popular adsorbant because it is

- Relatively inexpensive

- Adsorbs wide range of organic and inorganic substances.

- Can be made from several materials e.g wood, sawdust, fruit pits, coconut shells, coal lignite and petroleum residues.

To make activated carbon the chosen material is carbonized and then activated with hot air or steam. The extensive pore structure provides an extensive adsorption surface, which can range from 600-1100m²/g of active carbon.

In waste water treatment systems, multiple solutes often complete for adsorption sites on the activated carbon. Differences in carbon source, temperature swings and other systemspecific variances require that the pilot tests should be conducted before designing an activated carbon process.

Activated carbon is thought to remove a solute from solvent in 3 steps:-

- Transfer across a liquid boundry

- Sorption to the outer surface

- Migration into deep pores.

Many full-scale designs incorporate two or three columns. In two column design, one column regenerates, while the other is on-line. In three-column design, two columns operate in series while the third regenerates.

Disinfection of water

None of the previous methods used for treatment of waste water either singly or in combination can be relied upon to remove the bacteria present in water especially pathogenic one. Therefore it is necessary to disinfect or kill the bacteria. The methods employed to disinfect water depends upon the disinfecting materials used for the purpose. The general requirement is

1. It should be harmless and unobjectionable to the consumer

2. It should retain a residual disinfecting effect for a long time.

Principle methods used for disinfection are

1. Chlorination

2. Ozonization

3. Ultraviolet ray method

4. Excess lime method

5. Iodine and bromine methods

1) Chlorination

It is the application of small quantity of chlorine or chlorine compounds in water. The dose applied is generally less than 1mg/l so as to produce residual chlorine of trace quantity i.e 0.05-0.20mg/l. Chlorine hydrolysis in water to form hypochlorous acid (HoCl) which further dissociates to produce hypochlorite ion (ocl-). HoCl and oCl- together are known as free available chlorine. The reaction is as follows:

$$Cl_2 + H_2O \longleftrightarrow HOCL + H^+ + Cl^-$$

$$HOCl \longleftrightarrow H^+ + OCl^-$$
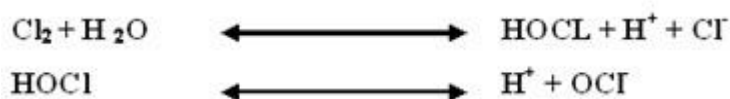
Chlorine is generally applied after all other treatments to the water has been given. This may be termed as post chlorination and is the standard treatment for all water works. There are however, other special methods of chlorination depending upon particular purpose.

i) Pre-chlorination: It is the application of chlorine preceding filteration. It reduces bacterial load on filters resulting in increased filter runs and oxidizes excessive organic mater thus removing taste and odour.

ii) Double chlorinaton: Application of chlorine at two points i.e prechlorination and to the final effluent.

Advantages are:

- Decreases in load of filters.
- Greater removal of bacteria –higher bacterial efficiency
- Greater factor of safety due to maintenance of 2 chlorinating plants.
- Control of algae and slimy growths in coagulating basins and filters.

iii) Superchlorination: It is the application of water with excess amount of chlorine i.e < 1mg/l to 2 mg/l this method is effective in destroying high concentratation of tastis and odours in water. Bacteria removal is also high.

iv) Breakpoint chlorination: It is also termed as free-residual chlorination which involves the addition of sufficient chlorine so as to oxidize a organic matter, reducing substances and free ammonia in raw water leaving behind mainly free available cl_2 which possess strong disinfecting action against pathogens.

2) Ozonization

It is a highly oxidizing agent containing 3 atoms of oxygen (O_3) which changes to O_2 and releases nascent oxygen (O). the nascent oxygen reduces organic matter present in water without production of objectionable tastes and odours as with chlorine.

The ozone dose is 2-3mg/l to give a trace to 0.1 mg/l residual after 10 minutes contact. It is regarded as a natural means of disinfecting water having bacterial spores. However, it is costly to manufacture, it has very little residuals presents, not quite suitable for highly turbid waters.

3) Ultraviolet rays

It is an effective method of disinfecting clear water which kills all type of bacteria, cysts and spores. Water is passed over a uv lamp as the effective penetration of rays in water is only for a depth of 30cm or so.

Advantages

- No taste and no odour

- Presenting no danger of overdose

Disadvantages

- High cost

- Absence of any residual action.

- Use in restricted normally to small installations like swimming pools.

4) Excess lime method

Excess lime method involves application of sufficient lime for the combined objectives of softening and disinfecting of water coliform reduction may be as high as 99%

- Dose given is between 10-20mg/l

- It frequently becomes necessary to remove excess lime after the process through recarbonation.

5) Iodine and Bromine methods

Their use is restricted to small water supplies such as army camps and swimming pools. Water which is muddy or colored needs to be filtered before disinfection. These are cheaply available in the form of pellets. Dosage is about 8-10mg/l. for heavily polluted water, it may be doubled only objection is the resulting medical taste.

Module 8. Presence of typical chemicals

Lesson 15. Microbiology of waste, bacteriological analysis of water, water borne diseases, insecticide, pesticide and fungicides residues

Water used in crop production involves field operations like irrigation, applications of pesticides and fertilizers. Therefore water has the potential to be a direct source of contamination and a vehicle for spreading localized contamination in the field, facility or transport environment. If the pathogens survive on the produce, they may cause food borne illness. Water can be a carrier of certain m/o's the list of which is given below :

Categories of organisms of public health significance

Pathogens and Parasites	Minimal Infective Doses
Salmonella spp.	10
Shigella spp.	10
Escherichia coli	10
Vibrio cholerae	10
Escherichia coli O157:H7	100
Campylobacter jejuni	about 500
Giardia lamblia	10
Cryptosporidium cysts	10
Entamoeba coli cysts	10
Ascaris	1–10 eggs
Hepatitis A virus	1–10 PFU

Most microbial contamination is on the surface of fruits and vegetables. If pathogens are not removed, inactivated, or otherwise controlled, they can spread to surrounding produce, potentially contaminating a significant proportion of the produce .Therefore washing fresh produce (also known as surface treatment) can reduce the overall potential for microbial food safety hazards. Also, Sanitizers or anti-microbial in wash water and other processing water may be useful in reducing pathogens on the surface of produce and/or reducing pathogen build-up in water.

The effectiveness of a sanitizer depends on its chemical and physical nature, treatment conditions (such as water temperature, pH, and contact time), resistance of pathogens, andthe nature of the fruit or vegetable surface. Chlorine is a commonly used anti-microbial. Chlorine dioxide, trisodium phosphate, organic acids, and ozone have also been used as anti-microbials in produce wash water. All chemical substances that contact food must be used in accordance with FDA and EPA regulations. Food-processing wastewater can be characterized as non toxic, because it contains few hazardous and persistent compounds. With the exception of some toxic cleaning products, wastewater from food-processing facilities is organic and can be treated by conventional biological technologies. Due to increased enforcement of discharge regulations and escalating POTW surcharges, many food-processing facilities are taking steps to either reduce, recycle(or renovate), and/or treat their wastewaters before they discharge them.

Another contaminant of food-processing wastewaters, particularly from meat-, poultry, and seafood-processing facilities, is pathogenic organisms. Wastewaters with high pathogenic levels must be disinfected prior to discharge.

Bacteriological Analysis of water

The bacteriological analysis of water is done primarily to determine the fitness of water. As many diseases are of intestinal origin e.g. typhoid fever, dysentery etc and are transmitted through contaminated water. It is very important to check the presence of coliforms in waste water as they are closely associated with the pathogenic organisms and a present in large numbers in polluted waters. On the other hand, detection of specific pathogenic organisms in water supply, because of their minute number is much more difficult.

The coliform group which derives its name from the colon or large intestine of man is inhabited by a particular genera called Escherichia coli or E. coli. this bacteria out numbers the other pathogenic microorganisms. Hence it serve as a very good indicator organisms and taste conducted to determine their presence.

Bacteriological analysis involves the following tests:-

1. Total count of Bacteria, also called standard plate count.

2. E. coli test

SPC test

The standard plate count provides an estimate of the total number of bacteria in a water sample, which will grow and develop in a particulate medium at a temp of 37°C (human body temp) for a period of 24 hrs under lab conditions.

Standard plate count through not of much use in ascertaining the sanitary quality of water, helpful in determining the bacterial efficiency of filteration units in water treatment plants.

E. coli test

It includes 3 tests

a) The presumptive test

b) The confirmed test

c) The completed test

a) The presumptive test: It consists of incubating water samples (diluted) along with lactose broth as a culture medium for 24-48hrs at 37°C. The sample is placed in standard fermentation tubes called Durhum tubes. The test is said to be positive if gas is evolved and negative if no gas is evolved. The negative presumptive test would indicate that the water is safe for use.

b) The confirmed test: this test is required as the production of gas in lactose broth doesnot necessarily indicate the presence of bacteria of coliform group, because there may be other bacteria present which also ferment lactose. If now, a portion of the broth from previous fermentation tubes showing gas is placed in other fermentation tubes containing brilliant lactose bile as the medium and incubation carried out as before i.e for 48hrs at 37°C. The formation of gas in these tubes would confirm the presence of the organisms of the the coliform group i.e *E.coli* the test is then said to be positive and water unsafe for use. The brilliant bile is used because it inhibits the growth of bacteria other than the coliform organisms.

c) The completed test: This test is not always necessary and is done sometimes to demonstrate with certainly that the organisms showing positive results for the confirmed test are really members of the coliform group. The test involves streaking of endo or eosin methylene blue plates from each brilliant green bile tube showing gas and incubating for 24 h at 37°C and then picking only discrete colonies well isolated and inoculating in lactose broth fermentation tubes and on agar slants and finally incubating for 48 h at 37°C. The formation of gas in lactose broth and the appearance of gramnegative non-spore forming bacilli are taken as a satisfactory completed test.

Water borne diseases

When water contains harmful and disease producing matter, it may lead to many disease on being consumed by healthy persons. The so called water borne diseases is caused by following factors.

a) Presence of micro organisms: Which originates from the intestinal disorders of infected persons.

e.g. Cholera is caused by vibrio cholera

Typhoid is caused by salmonella typhi

Hepatitis A is caused by Hepatitis A

b) Presence of Parasitic ova: The eggs or developed embryo of round worm and tape worms are generally carried by water and causes diseases.

c) Presence of inorganic matter: Certain diseases may result from the presence or absence of certain minerals in waters. Some minerals may be toxic by their more presence while others become toxic when their quantity exceeds a certain limit eg lead, arsenic, fluorides, sulphates of magnesium, Iodine etc.

d) Presence of organic matter: An excess of organic matter in the water may lead to diarrhea and other gastric disturbances in the human body. The complete control of water borne diseases involves instituting an environmental health programme that incorporates personal and household hygiens control of fly species and other insects monitoring of food processing, immunization of population where possible and proper scientific waste disposal and water treatment to remove harmful constituents.

Insecticide, pesticides and fungicides residues

Additives are used in the food processing industry to facilitate plant operations and provide sanitation. These chemicals often pass through the plant and may interfere with the disposal of process waste. In addition, chemicals are used to preserve food, control moisture, control texture, enhance flavour, decrease cooking/preparation time and enhance nutritional value. The vast majority of these chemicals remain in the product and are not found in the waste streams in significant concentrations. Four categories of chemicals that are of importance to wastewater treatment and disposal are commonly used at food processing plants to facilitate operations.

• Ligands

• Pesticides

• Sanitizers

• Surfactants

Ligands

Ligands are also called complexing or sequestering agents. Their primary use is to reduce scaling. Scaling can build up rapidly and leads to clogged pipes, inefficient heat exchange and uneven temperatures. Scale that flakes off can enter machinery and cause premature wear .A ligand is an ion with a bonding site that can donate an electron pair in order to form a bond with a metal ion. Chelating agents are ligands with two or more bonding sites. Ligands are sorted into three categories, organic acids, phosphates and phosphonates. Organic acids are the strongest.

- Organic Acids
- Aminopolycarboxylic acids (ACPAs)

- Ethylenediaminetetraacetate (EDTA)

- Nitrilotriacetate (NTA)

- Diethylene-triaminepentaacetate (DTPA)

- Hydroxyethylenediaminetriacetate (HEDTA)

- Hydroxycarboxylic acids - Citric acid

- Phosphates - Sodium polyphosphates

- Phosphonates - Organophosphonates

Pesticides

Pesticides reduce pests in the food processing plant such as rodents, insects and fungi.

Large quantities may be used in facilities that handle fresh produce. Additionally, residual pesticides on the commodity may enter the waste stream during washing. Pesticides are sorted into three categories, insecticides, herbicides and fungicides. Categories are further divided up into classes of chemicals with common examples listed, with the exception of fungicides which are not widely used food processing industry

Insecticides

Carbamates (Aldicarb, Carbaryl, Carbofuran)ƒ

Organochlorines (Methoxychlor, Endosulfan, Lindane)ƒ

Organophosphates (Chlorpyrifos, Diazinon, Malathion)ƒ

Pyrethroids (Cypermethrin, Cyfluthrin, Esfenvalerate)

Herbicides

Benzoic acids, Paraquat, Phenoxy acids, Substituted ureas, Triazines

Sanitizers

Sanitizers are used to deactivate bacteria on food contact surfaces. The more concentrated the sanitizer is, the more damaging it is to microbial populations.The mechanisms vary but are generally the physical destruction of the cells and/or inactivation of cell function at the genetic level. Sanitizers can be divided into two categories, oxidizing agents and non-oxidizers. Oxidizing sanitizers may be further categorized as either halogen or peroxygen. Organic bromine compounds work synergistically with many chlorine compounds. Non-oxidizing sanitizers include acid sanitizers, acid anionic sanitizers, acid-quat sanitizers and quaternary ammonium compounds.

Surfactants

Surfactants lower the surface tension of a solvent, such as water. This allows other cleaning compounds to penetrate a water film surrounding a dirt particle so that bonds can be formed. There are four types of surfactants: anionic, cationic, non-ionic and amphoteric. Anionic surfactants account for 50% of surfactant use in Europe and 60% in the United States. The balance, roughly 40%, is non-ionic surfactants.

Anionic surfactants

Alkyl sulfates

Ether carboxylates

Ether sulfates

Isethionate esters

n-Acylated amino acids

Phosphate esters

Sulfonates

Sulfosuccinate esters

Nonionic surfactants

Alkyl polyglycosides

Amine oxides

Esters of polyhydroxy compounds

Ethoxylated compounds

Fatty acid alkanolamide

Lesson 16. Management of Pesticide Residues, equipments for estimation of pesticide residue.

The use of pesticides has become indispensable in present agriculture to control pests on fruits and vegetables. The farmers frequently use pesticides to save their crops and earn more profit. Though the pesticides are useful to control pests yet they have their own drawbacks. They leave harmful residues on the edible portion of fruits and vegetables. Pesticide residue means any substance resulting from the use of pesticide which may include conversion products, reaction products, metabolites or impurities of toxicological significance. These may be present in fresh or processed fruit and vegetable, or food and drink made from the crop. Residues may result from direct use of pesticides on food crops or environmental or other indirect sources. The animal products like milk and meat and their products may contain pesticide residues if the animals are fed on feed or fodder contaminated with the residues. Persistence of insecticide residues on a particular crop/environment depends on a number of factors and the important ones are:

- Chemical nature of the insecticide
- Amount (dose) applied
- Crop/variety
- Interval between application and harvest
- Weather conditions
- Frequency of application
- Formulation of pesticide
- Application equipment/operator

Management of pesticide residues

In order to minimize risk from exposure of pesticide residue, farmers must observe waiting period before harvesting vegetable or fruit and the waiting period for different insecticide on different crops will vary. It may also vary for one insecticide on a particular crop at two different places. In some cases, the insecticide is applied at the time of sowing/planting and the residues are estimated at the time of harvest due to persistent nature of such insecticides. In such cases these waiting periods are taken as days at harvest and may appear to be very long intervals.

Guidelines for farmers

Farmers should use pesticides only when absolutely necessary. Whenever possible, prefer non-chemical methods of pest control. Apply only recommended pesticides at recommended dosages. Use low persistent pesticide. Do not apply persistent pesticide on vegetable, fruit, fodder crops or directly on animals for control of ticks. Ripe fruits and vegetables should be plucked before pesticide application. After pesticide use, harvest crop only after recommended waiting period. The Punjab Agricultural University has worked out waiting periods for commonly used pesticides on commercially grown fruits and vegetables which are given in the following table:

Waiting period (days) of insecticides on different vegetable crops and fruits

Sr. No	Insecticide	Waiting period (days)	Crop(s)
1.	Endosulfan	1	Brinjal, okra, tomato
		2	Grapes
		3	Cauliflower
2.	Carbaryl	1	Tomato
		3	Cabbage, okra
		10	Cauliflower
		15	Grapes
3.	Malathion	1	Brinjal, cabbage, okra
		7	Grapes
4.	Monocrotophos	1	Brinjal
5.	Quinalphos	3	Brinjal
		4	Tomato
		5	Cabbage, Cauliflower
6.	Triazophos	7	Cauliflower
7.	Diazinon	4	Cabbage
8.	Cypermethrin	1	Okra, Brinjal, cabbage, cauliflower, tomato
9.	Fenvalerate	1	Brinjal, cabbage, cauliflower, tomato
		3	Okra
10	Dimethoate	1	Guava, peach
11	Carbofuran	6	Peach
12	Mancozeb	5	Tomato
13	Synthetic pyrethroids	1-2	Tomato, cabbage, cauliflower, Brinjal and okra

Guidelines for consumers

Residues are left behind in the crop after harvesting or storage and make their way into the food chain. They can remain even when pesticides are applied in the right amount and at the right time. The consumer must be made aware of the harmful effects of pesticides. The following steps, if followed, will limit the amount of pesticide residues we eat.

Pesticide residues on food commodities especially fruits and vegetables can be reduced by washing under tap water. Washing with dilute salt solution is convenient method to lower the load of contaminants from food surfaces e.g. in case of green chillies, where dipping in 2 per cent salt solution for 10 minutes followed by washing removes cypermethrin, triazophos and acephate residues. Washing potatoes with tap water or aqueous solution of acetic acid or sodium chloride removes residues. Washing of okra, tomato, brinjal and beans removes malathion, carbaryl and endosulfan residues. Chlorinated (500 ppm) and ozonated (25 ppm) water causes reduction of 50 – 100% of residues in apple. Washing with 0.1% liquid detergent removes 70 % residues of dieldrin and heptachlor epoxide. Alternately blanching of vegetables in boiling water for one minute reduces residues. Combining both washing and blanching can reduce the pesticide residues to greater extent.

Peeling is the most effective method to remove residues from vegetables. Outer portions of celery, lettuce, cabbage and other leafy vegetables may contain the bulk of pesticide residues. Remove the outer leaves of leafy vegetables such as lettuce and cabbage to get rid of pesticides. Residues of some pesticides concentrate in animal fat. Trim the fat from meat, and fat and skin from poultry and fish for removal of pesticides. Peeling and washing help to remove residues of certain insecticides which are not systemic and found only in the pericarp of fruits. Processing, including cooking, reduces the level of pesticides as this breaks down the pesticides. Eat a wide variety of fruits and vegetables, not limiting to only one. This would limit the exposure to any one type of pesticide. Avoid offseason vegetables, because farmers use sprays to earn more profit, as the cost of offseason vegetables is high in the market. Vegetables and fruits should not be grown near open drains and irrigating fields/orchards with sewerage water should be avoided. Proper storage and handling of produce also reduces the presence of mycotoxins.

The pesticides should be used judiciously and to achieve, the cooperation of farmers and consumers is required to reduce the pesticide load and residue problems.

Equipments used for estimation of pesticide residue

Microwave Digestive System (MDS

It is an instrument used for the preparation of sample for atomic absorption system analysis. The digestion process lasts for 45 minutes. For this process super pure nitric acid is being used. After every three digestions, the system needs to be cleaned by a recommended method as the samples for AAS needs to be clarified. For water sample, first its acidification is required.

Fig. 16.1 Microwave Digestive System (MDS)

Atomic Absorption Spectrophotometer (AAS)

It is a spectro-analytical procedure for quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state. The apparatus/system comprised of three modules namely Furnace, Fias and Flame. The detection in the furnace and fias mode is upto ppb level while for flame, its in PPM level. Two types of lamps are used in them (1) EDL (2) HCL. Principle requires standards with known analyte content to establish the relation between the measured absorbance and the analyte concentration and relies therefore on the Beer-Lambert Law.

Fig. 16.2 Atomic Absorption Spectrophotometer (AAS)

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High Performance Liquid Chromatography (HPLC)

It is a chromatographic technique used to separate a mixture of compounds in analytical chemistry and biochemistry with the purpose of identifying, quantifying or purifying the individual components of the mixture. HPLC is considered on instrumental technique of analytical chemistry. It has many uses including medical (eg-detecting performance enhancement drugs in wine), research (eg. Separating the components of a complex biological sample or of similar synthetic chemicals from each other) & manufacturing (during the production process of pharmaceutical & biological products).

Fig. 16.3 High Performance Liquid Chromatography (HPLC)

Gas Chromatography (GC)

Gas chromatography is a technique used to separate drugs / pesticides that might be present in a sample. The sample is injected into a long tubular column. The drugs are swept through the column by a stream of helium gas. A samples individual chemical characteristics determines how long it will take to go through the chromatography column. The time it takes for any given sample to travel the length of the column is refreshed to as its Retention Time (RT). It forms an identifying characteristic.

Fig. 16.4 Gas Chromatography (GC)

Mass Spectrometry (GC MS)

The detector for the GC is the Mass Spectrometry detector. As a samples exits the end of the GC column it is fragmented by ionization and fragments are sorted by mass to form a fragmentation pattern like the Retention Time (RT), the fragmentation pattern for a given sample is unique and is an identifying characteristic of the sample.

Fig. 16.5 Mass Spectrometry (GC MS)

List of instruments/ equipments for pesticide estimation in foods

Sr. No.	Name of Instruments	Model / Make	Function/ Analysis
1.	HPLC	M – 600 E/ Waters	Pesticides (Non volatile)
2.	Gas Chromatograph	GC – 17 AATF Ver. 3/ Shimadzu	Pesticides (Volatile)
3.	GC-MS	Perkin Elmer	Food analysis
4.	Atomic Absorption Spectrophotometer	AANALYST – 800/ Perkin Elmer	Elements (heavy metals, micronutrients in water and food samples)
5.	Micro wave Digestion System	Multiwave 3000/ Perkin Elmer	Sample preparation for AAS
6.	Millipore HPLC Grade water Generator	Millipore	Deionized water
7.	Tissue Homogenizer	Swastika Electric & Scientific Works	Sample preparation for pesticide residue analysis
General Quality Analysis equipments as well as used for pesticide residue and heavy metal analysis			
1.	Colour Difference Meter	Mini Scan XE Plus/ Hunter Lab	Colour
2.	Digital Balances 2 Nos. (4 decimal point)	Mettler Toledo	Weighing
3.	UV-VIS Spectrophotometer	S – 200 (Specord-200)/ Analytica Jiva	General Quality Analysis and Pesticide Residue Analysis

4.	Moisture Analyzer	HR 73/ Mettler Toledo	Moisture
5.	Vacuum oven with multifunctional microprocessor	VD 115/ Binder	Preparation of samples in general quality analysis
6.	Water Distillation Set	Mono Dust 3000 E/ Germany	Distilled water
7.	Refrigerated Centrifuge	3 K 30/ Sigma	Centrifuging
8.	Micropipettes 5 Nos.	Brand Germany	Sample measurement
9.	Hand Refractrometer 4 Nos.	ERMA Japan	TSS
10.	Digital pH meter Bench top 2 Nos.	MP 230 K (Mettler Toledo)	pH measurement
11.	Digital pH meter Portable 2 Nos.	120 (Mettler Toledo)	pH measurement
12.	Digital Balance cap. 42/210 g. (5 decimal point)	GR 202/ A & D	Weighing
13.	Hot plate with magnetic stirrer	SPINOT/ Tarson	Sample preparation
14.	Hot Air Oven	Universal, India	Moisture
15.	Refrigerators 4 Nos.	GR 322 SVF/ LG	Sample/ chemical storage

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