CHAPTER 02

Biochemical Reactions in Treatment of Waste Water

INTRODUCTION

In relation to drinking water, micro-organisms are potentialy hazardous whereas in waste water treatment they can be very beneficial in stabilizing harmful pollutants. Micro-organisms are found almost everywhere in nature and most are useful members of the ecological community, and plays a major role in wastewater treatment operations. This is because sewage and many other waste waters contains considerable amount of colloidal and soluble organic substances which are most easily broken down by biochemical reactions.

2.1 Biochemical Reactions

- The Aerobic and Anaerobic are the two basic forms of biological stabilisation reactions whose occurrence is dependent upon the availability or otherwise of dissolved oxygen.
- The Aerobic reactions take place in the presence of free oxygen and produce reasonably stable inorganic end products with relatively low energy contents. A considerable portion of the organic matter is synthesised to new microbial cells.
- A reaction is attractive for wastewater treatment because of the high degree of stabilisation although the synthesised micro-organisms result in the formation of large volumes of sludge which require further treatment.
- The Anaerobic reactions occur only in the absence of free oxygen and are more complex because they occur in two stages carried out by different species of bacteria.
- The acid-forming bacteria initially convert complex organics into organic acids and alcohols. At this point methane-forming bacteria convert the acids and alcohols into methane and other end products such as hydrogen sulphide.
- The end products of anaerobic reactions still contain considerable amounts of energy, notably in the methane.
- Because of the lower release of energy in anaerobic reactions, the synthesis of new cells is very much less than in aerobic reactions.

- This means that there is less sludge, from anaerobic stabilisation of a wastewater than from aerobic stabilisation of the same wastewater.
- Anaerobic reactions are much slower than aerobic reactions and do not usually remove the organic content of the food to such a low level as is possible in an aerobic reaction.

NOTE: In anaerobic process, bonded O_2 is bonded from the molecules and thus energy released in anaerobic process is less and hence synthesis of new cell is less.

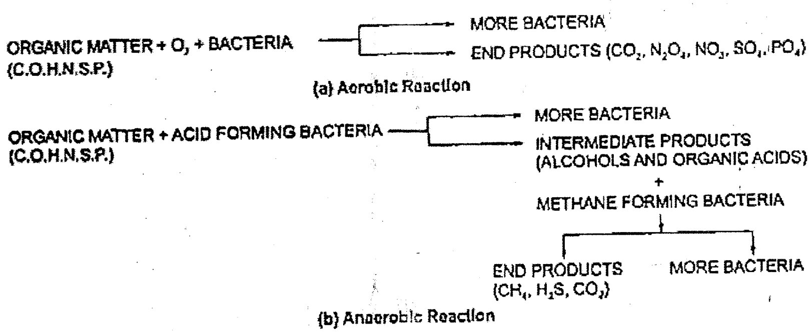

Fig.2.1 Biochemical Reactions

2.2 Biological Growth

- In all biological reactions, energy in the organic substrate is split into three ways energy in new microorganisms, energy in the end product and heat energy.
- The proportions of energy in the three directions depends upon the nature of the organic matter, the micro organisms carrying out the reaction and the environment in which the reaction takes place.
- Catabolic reactions are those in which food is broken down to release energy. reaction which release energy for synthesis of new microbial cells are termed anabolic.
- In autolysis, synthesised microbial cells are themselves oxidised and energy is released. Biological reactions are controlled by organic catalysts which are termed as enzymes.
- Enzymes are high molecular weight substance which are introduced by microorganisms and which are highly specific for particular organic substances and types of reactions.
- In biological treatment processes the materials to be stabilized provides the basic nutritional and energy requirement for its conversion into end products and new microorganisms.
- In the absence of organic matter, microorganisms can exist for some time because of the existence of auto-oxidation or endogenous respiration. In endogenous respiration which takes place continuously in biological system, cell die and lysis to release organic matter and nutrients back into the system where they can be reused.

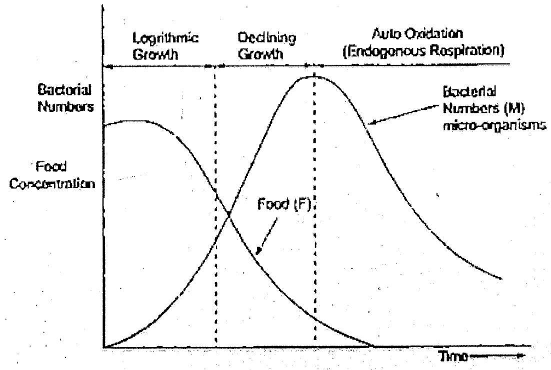

Fig.2.2 Biological Growth Curve for a Batch System

- Biological growth in the oxidation system assumes the following:
  - (i) Sample supplies of carbon nitrogen and phosphorous so as to enable the synthesis of new cells, the empirical formula for which is

    $$C_{60}H_{87}O_{23}N_{12}P$$

    BOD_5 : N : P ratio of 100 : 5 : 1 or C : N : P ratio of 100 : 15 : 3
  - (ii) Sufficient energy is available in the organic matter.
  - (iii) Inorganic growth nutrients such as calcium, cobalt, iron manganese, potassium etc. are present in the small amounts necessary.
  - (iv) Appropriate vitamin growth nutrients are present and
  - (v) Absence of toxic substances such as heavy metals (e.g Cd, Pb, Cr, Ni, C, N) etc.
- Domestic sewage satisfies all of these requirement and, indeed it has an excess of nitrogen and phosphorous.
- Industrial wastewater may be lacking in some essential components and nutrient supplementation may be needed for effective biological treatment.

NOTE The end products of aerobic catabolism are low energy, stable compound with most of the energy being stored in the cellular material. By contrast, most of the energy released in anaerobic catabolism remains in the waste products.

- It is important to reduce the concentration of toxic substances to innocuous levels when industrial wastewaters are to be treated, thus the need for the pretreatment of industrial wastewater before discharge into municipal sewerage system arises.

2.3 Decomposition of Sewage

The organic matter, which is decomposed by bacteria, under biological action, is called biodegradable organic matter. Most of the organic matter present in sewage is biodegradable and hence undergo biological decomposition, which can be divided into two types.

2.3.1 Aerobic Decomposition

If air or oxygen is available freely to the wastewater in dissolved form, then the biodegradable organic matter will undergo aerobic decomposition, caused by aerobic bacteria as well as by facultative bacteria—operating aerobically. These bacteria will then utilize the free oxygen as electron acceptor, thereby oxidizing the organic matter to stable and unobjectionable end products. The stable end products like nitrates, carbon dioxide, sulphates are formed, respectively for the three forms of matter, i.e., nitrogenous, carbonaceous and sulphurous matter. Water, heat and additional bacteria will also be produced in this biological oxidation, which can be represented by the following equations:

(i) Nitrogeneous organic matter $\xrightarrow[\text{Aerobics}]{\text{Oxidation by}} NO_3^- + \underset{\text{(sometimes)}}{NH_3} \uparrow + \text{Energy}$

(ii) Carbonaceous organic matter $\xrightarrow[\text{Aerobics}]{\text{Oxidation by}} CO_2 \uparrow + H_2O + \text{Energy}$

(iii) Sulphurous organic matter $\xrightarrow[\text{Aerobics}]{\text{Oxidation by}} SO_4^{--} + \text{Energy}$

It may also be noted that during the decomposition of nitrogenous organic matter, the ammonia formed in the initial stages, may linger on till the end, depending upon the available oxygen, retention time, temperature, biological activity, etc., because the facultative bacteria are incapable to break ammonia to nitrates.

The intermediate products formed in the aerobic oxidation of the three types of organic matter are shown in their respective cycles, in Fig. 2.3, 2.4 and 2.5. These cycles, for nitrogenous, carbonaceous, and sulphurous organic matter, respectively.

2.3.2 Anaerobic Decomposition

- If free dissolved oxygen is not available to the sewage, then anaerobic decomposition called putrefaction, will occur.
- Anaerobic bacteria as well as facultative bacteria-operating anaerobically, will then flourish and convert the complex, organic matter into simpler organic compounds of nitrogen, carbon and sulphur.
- These anaerobic bacteria infect survive by extracting and consuming the bonded molecular oxygen present in compounds like nitrates (NO_3), and sulphate (SO_4).
- Gases like ammonia, nitrogen, hydrogen sulphide, methane etc. are also evolved in this decomposition, producing obnoxious odour.

2.3.2.1 Step In the Nitrogen Cycle

(i) Nitrogenous organic matter get oxidised to ammonia, then to nitrites and finally to nitrates. Which when consumed by plants, through photosynthesis, from plant proteins.

(ii) The plant proteins, when consumed by animals, form animal proteins. The wastes produced by animals and their dead bodies, will again form nitrogenous organic matter, thus completing the nitrogen cycle.

(iii) There may be some short circuit cycle, as shown by dotted line.

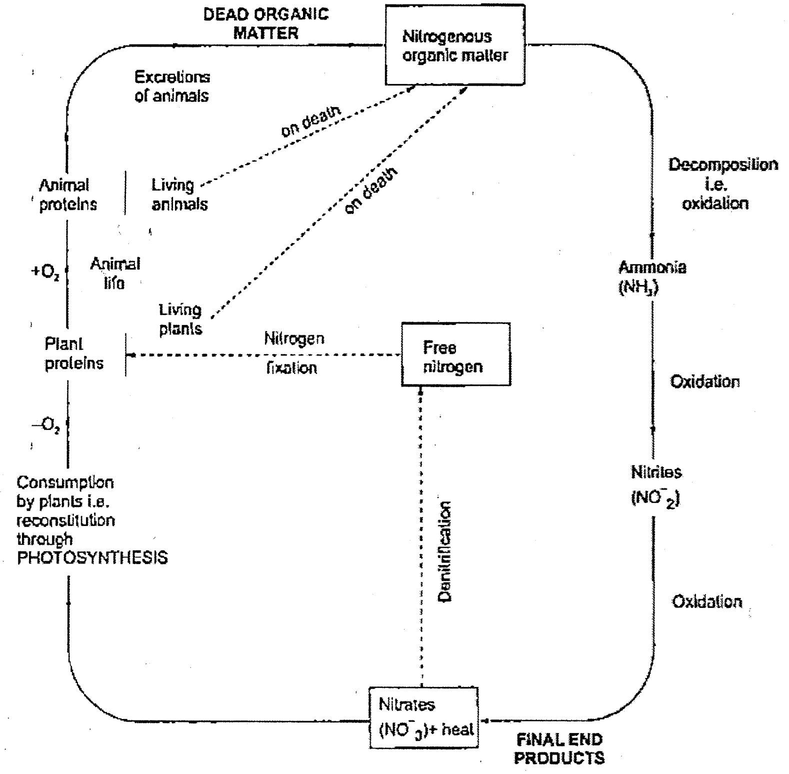

Fig. 2.3 Nitrogen cycle under aerobic oxidation

NOTE

1. Nitrates on denitrification may get converted into free nitrogen (and sometimes to ammonia), which may be converted into plant proteins, as it may be used by certain bacteria residing in the plant roots. This is called nitrogen fixation.
2. Blue green algae also causes nitrogen fixation.

2.3.2.2 Step in the Sulphur Cycle

(i) This cycle is similar to nitrogen cycle. The sulphurous organic matter on oxidation produces H_2S gas, which on further oxidation, changes to sulphur and then finally to sulphates (SO_4^{--})

(ii) Sulphates, when consumed by plants through photosynthesis, change into plant proteins; which when eaten by animals change into animal proteins.

(iii) The wastes produced by animals and their dead bodies will again form sulphurous organic matter, thus completing the sulphur cycle.

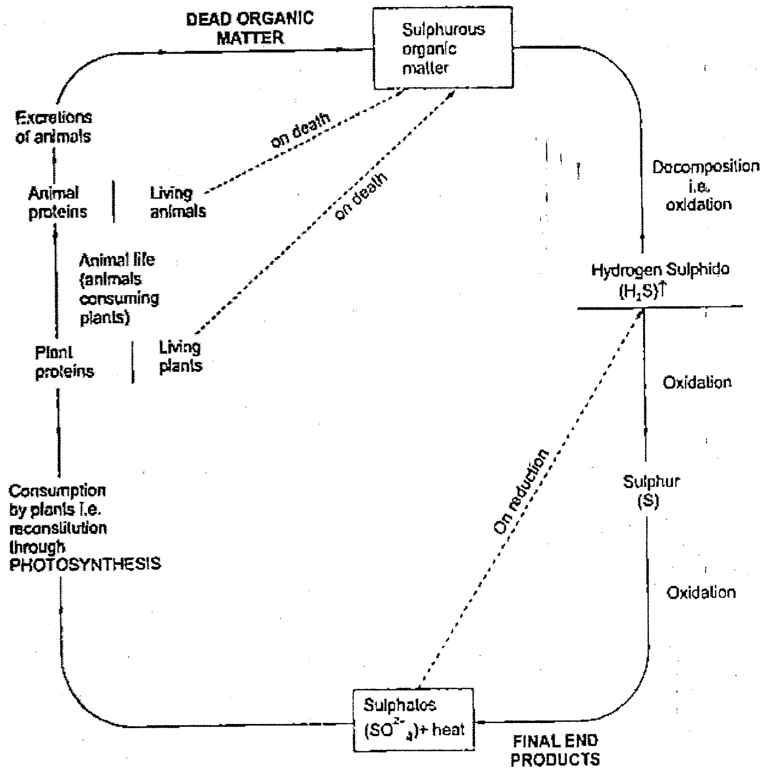

Fig. 2.4 Sulphur cycle under aerobic oxidation

(iv) There may be short circuits in the cycle as shown by the dotted lines. Organic sulphurous matter may be directly formed by the death of the plants without the formation of animal proteins.

NOTE: Sulphates in the absence of oxygen will be converted into H_2S by the process of reduction.

2.3.2.3 Step in the Carbon Cycle

(i) The Carbonaceous organics matter on oxidation, releases carbon dioxide, which is its final end product.

(ii) This CO_2, when used by plants through photosynthesis, gets converted into plant carbohydrates, fats, proteins; which when eaten by animals change into animal fats and proteins.

(iii) The waste produced by animals and their dead bodies will again form carbonaceous organic matter, thus completing the carbon cycle.

(iv) The plant life gives off CO_2 at night, and the animal life gives off CO_2 during respiration. Both these respiration processes are shown by the dotted lines in the figure.

(v) There may be short circuits in the cycle as shown in the dotted lines organic carbonaceous matter may be directly formed by the death of plants.

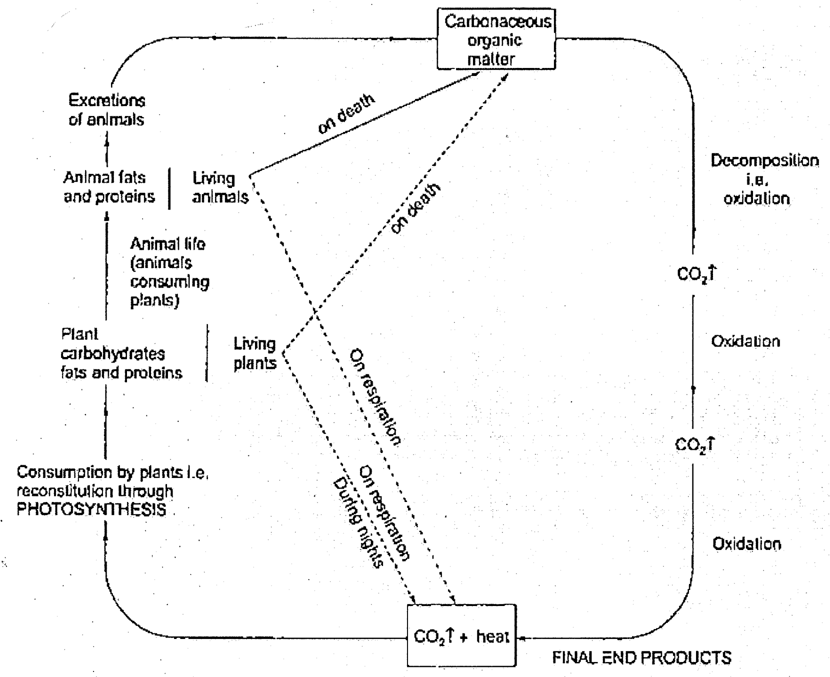

Fig. 2.5 Carbon cycle under aerobic oxidation

The various stages at which these gases are evolved are shown in figure below, which represents nitrogen, carbon and sulphur cycle together. The final equation, representing this decomposition are given below:

(i) Nitrogenous organic matter $\xrightarrow[\text{Anaerobics}]{\text{Reduction by}}$ $N_2\uparrow + NH_3\uparrow$ + organic acids + Heat energy

(ii) Carbonaceous organic matter $\xrightarrow[\text{Anaerobics}]{\text{Reduction by}}$ $CO_2\uparrow$ + Heat energy

(iii) Sulphurous organic matter $\xrightarrow[\text{Anaerobics}]{\text{Reduction by}}$ $H_2S\uparrow$ + Heat energy

(iv) Organic acids $\xrightarrow[\text{Anaerobics bacteria}]{\text{Methane forming}}$ $CH_4\uparrow + CO_2\uparrow$ + Heat energy

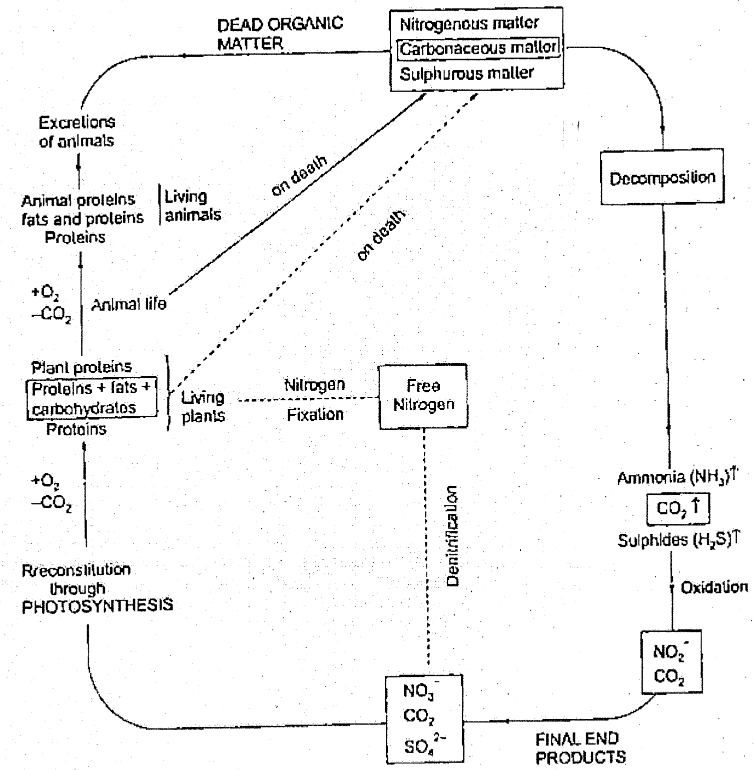

Fig. 2.6 Nitrogen, carbon and sulphur cycles, under anaerobic oxidation

- An understanding of these cycle will help us in determining the stage of decomposition of sewage by testing for the products of decay.

NOTE

A well oxidised sewage will contain nitrate and sulphates but very little ammonia and hydrogen sulphide. On the other hand, lesser oxidised sewage will contain nitrites and sulphur instead of nitrates and sulphates.

Table: 2.1 Distinguishing Features of the Aerobic Oxidation and Anaerobic Oxidation Processes

Parameter	Aerobic Oxidation	Anaerobic Oxidation
Oxygen requirement	Abundant	Nil
Areas of application	Commonly dilute liquid waste and solid waste composting	Commonly sludges
Energy release (per gram-mole glucose)	484 - 674 Kcal	26 Kcal
Stages required for process completion	1	2
Decomposition and Products	CO_2, H_2O, NO_3	NH_3, H_2S, CO_3, CH_2
BOD_5 of effluent	Low (less than 60 mg/*l*)	High (upto 5000 mg/*l*)
Operative bacterial species	Mesophillic and Thermophillic	Generally mesophillic
Process responsible for bacterial inactivation (composting included)	High heat release during bio-oxidation	Mainly acidic and unfavourable reaction media

2.4 Various Types of Bacteria

- Bacteria are primary decomposers of organic material. They utilize soluble food.
- Bacteria requires energy and material for growth and reproduction.
- Energy for bacteria is derived from biochemical oxidation or oxidation of inorganic or organic compounds.
- Material is derived from inorganic and organic compounds
- Bacteria are classified according to the energy or material source they require;

Autotrophs: They derive both energy and material from inorganic substance

Heterotrophs: They derive both energy and material from organic compounds.

Phototrophs: Utilise sunlight as energy source and inorganic substance for material source.

Heterotrops bacteria are the most important species in the degradation of organic matter.

Aerobic Heterotrophs: Aerobic bacteria (normally called) utilises organic in the presence of oxygen.

Anerobic Heterotrophs: Aerobic bacteria utilises organic in the absence of oxygen.

Facultative Heterotrophs: Facultative bacteria is capable of functioning both in the presence as well as absence of oxygen.

Summary

- The Aerobic form of biological stabilisation reaction is more attractive because of the high degree of stabilisation although formation of large volume of sludge.
- Energy released in aerobic oxidation is 484-674 kcal while in anaerobic oxidation only 26 kcal.
- BOD_5 of effluent in aerobic oxidation is low (less than 60 mg/*l*) while in aerobic oxidation is high (upto 5000 mg/*l*).

Objective Brain Teasers

Q.1 The main constituents of gas generated during the anaerobic digestion of sewage sludge are
(a) carbon dioxide and methane
(b) methane and ethane
(c) carbon dioxide and carbon monoxide
(d) carbon monoxide and nitrogen

Q.2 What is eutrophication of lakes primarily due to?
(a) Multiplication of bacteria
(b) Excessive inflow of nutrients
(c) Increase in benthic organisms
(d) Thermal and density currents

Q.3 Shallow ponds in which dissolved oxygen is present at all depths are called
(a) aerobic lagoons (b) aerobic ponds
(c) facultative lagoons (d) facultative ponds

Answers

1. (a) 2. (b) 3. (b)

Hints and Explanations:

Ans.2 (b)

Eutrophication is a natural process under which lakes get infested with algae and silt up gradually to become shallower and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorous. This natural process of eutrophication in fact can always get its carbon and nitrogen requirements from the atmospheric gases like CO_2 and NO_2; while the requirement of phosphorous is met by its presence in natural run off due to disintegration of rocks, which produce phosphorous. The increased phosphorous in lake water, will cause accelerated eutrophication of lakes and is called cultural eutrophication.

Ans.3 (b)

Shallow ponds in which dissolved oxygen is present at all depths are called aerobic ponds. Although some oxygen is provided by diffusion from the air, the bulk of the oxygen in ponds is provided by photosynthesis. Lagoons are distinguished from ponds in that oxygen for lagoons is provided by artificial aeration.

When sufficient energy is supplied to keep the entire contents, including the sewage solids, mixed and aerated, the reactor is called an aerobic lagoon. When only enough energy is supplied to mix the liquid portion of the lagoon, solids settle to the bottom in areas of low velocity gradients and proceed to degrade anaerobically. This facility is called a facultative lagoon, and the process differs from that in the facultative pond only in the method by which oxygen is supplied.

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