BIOLOGICAL BIOFILM PROCESSES

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PRESENTATION LAYOUT

- **Introduction**
- **Biofilm**
  - **Physical and Chemical Properties**
  - **Kinetics of Biofilm Systems**
- **Biological Biofilm Systems**
  - **Trickling Filter**
  - **Fludized Bed**
  - **Packed Bed**

INTRODUCTION

- Used for removal of organic pollutants from wastewaters
- Biological treatment is popular due to:
  - low cost
  - effective in removal of a wide range of organic contaminants
  - effective in removal of colloidal organics
  - can remove toxic non-organic pollutants such as heavy metals

Principles of Biological Processes

- Aerobic:

$$\text{Organic matter} + O_2 \rightarrow CO_2 + H_2O + \text{cell} + \text{energy}$$

- Anaerobic:

$$\text{Organic matter} \xrightarrow{N_1P} \text{intr.} + CO_2 + H_2O + \text{cell} + \text{energy}$$

$$\text{intermediates} \xrightarrow{N_1P} + CH_4 + CO_2 + \text{energy}$$

Process Limitations in Treating Hazardous Wastewater

- Acclimation period is usually required
- Sensitivity of the microorganisms to shock loading
- Processes may produce by-products that are more toxic than the initial substance
- Certain industrial wastewater required pretreatment
- Temperature should not exceed 110°F (43 ° C)

BIOFILMS

- Definition:

  "A gelatinous layer consisting of cells immobilized in an organic polymer matrix of microbial origin"

Physical Characteristics

- Thickness ranges from few microns to over 1000 microns
- Surface is irregular "rough"
- Specially heterogeneous
- Consists of two compartments:
  - Base film
  - Surface film

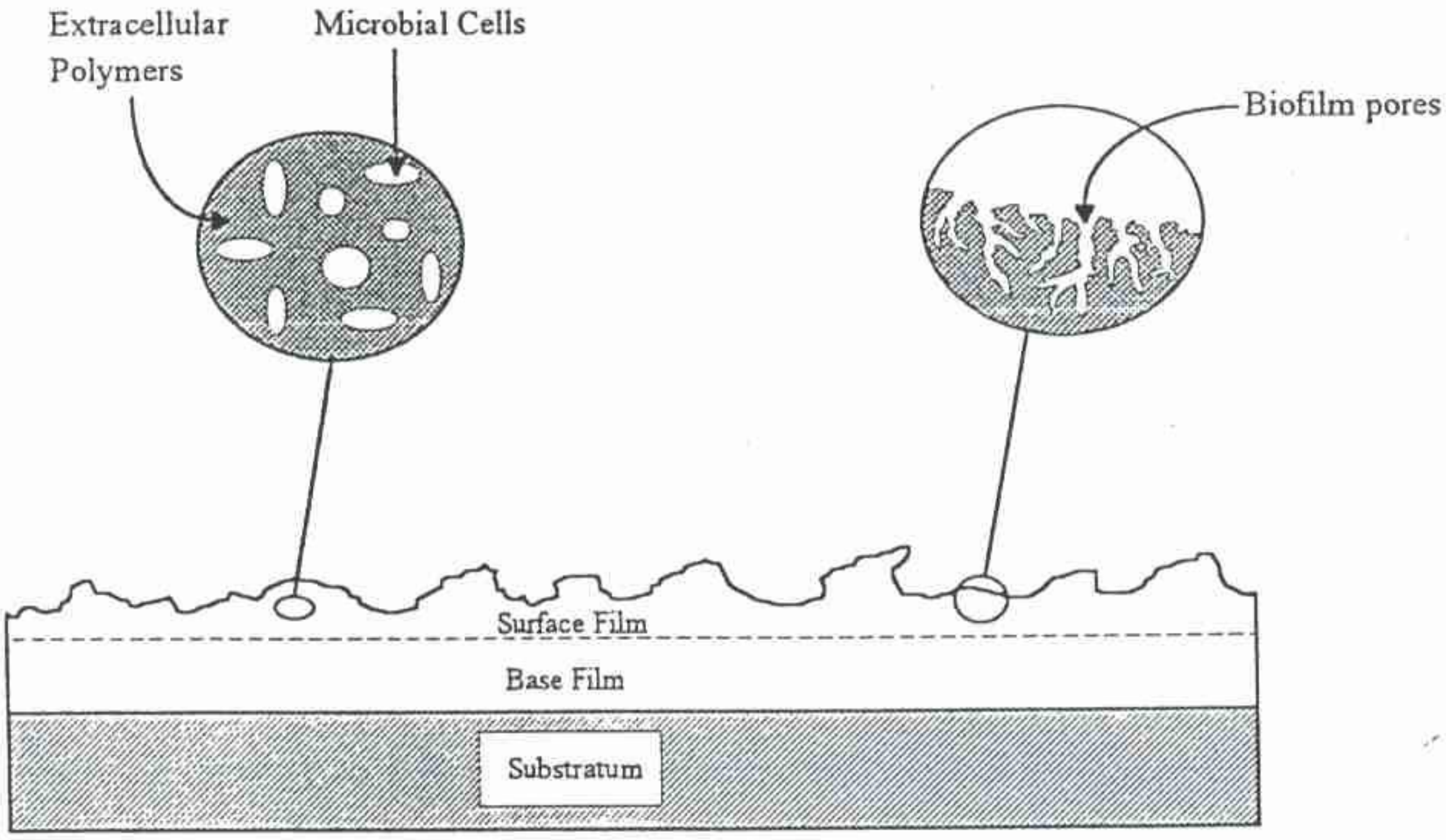


Figure 2a Cross-sectional view of the old conceptualization of the biofilm.
(Schematic diagram after Carlson, 1995)

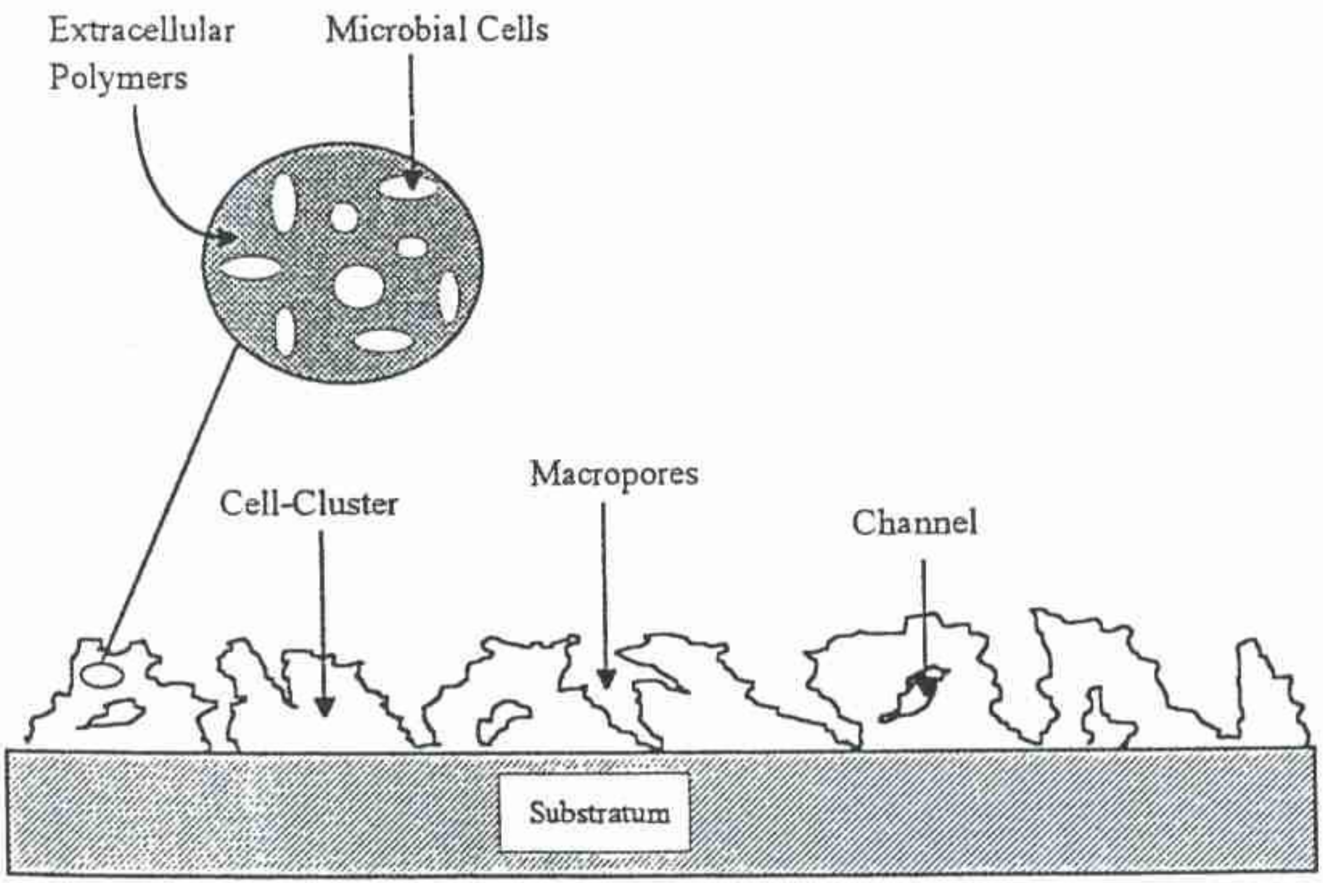


Figure 2b Cross-sectional view of the new conceptualization of the biofilm.
(Schematic diagram after Carlson, 1995)

Chemical Properties

- **The Extra-Cellular Polymers (EPS) give the biofilm its chemical properties**
- **EPS compounds are dominated by hydroxyl and carboxylic groups (OH^-, COO^-)**
- **The biofilm has a net anionic charge which influence transport of contaminants**

Kinetics of Biofilm Systems

Physical mass transport:

The rate of mass transport of substrate from the bulk liquid across a unit area of the stagnant liquid layer to the biofilm surface is called the flux.

$$N_s = K_L (S_b - S_s)$$

where:

N_s = flux in units of mass per unit area per unit time

K_L = mass transfer coefficient, length per time

S_b = substrate concentration in the bulk liquid

S_s = substrate concentration at the biofilm surface

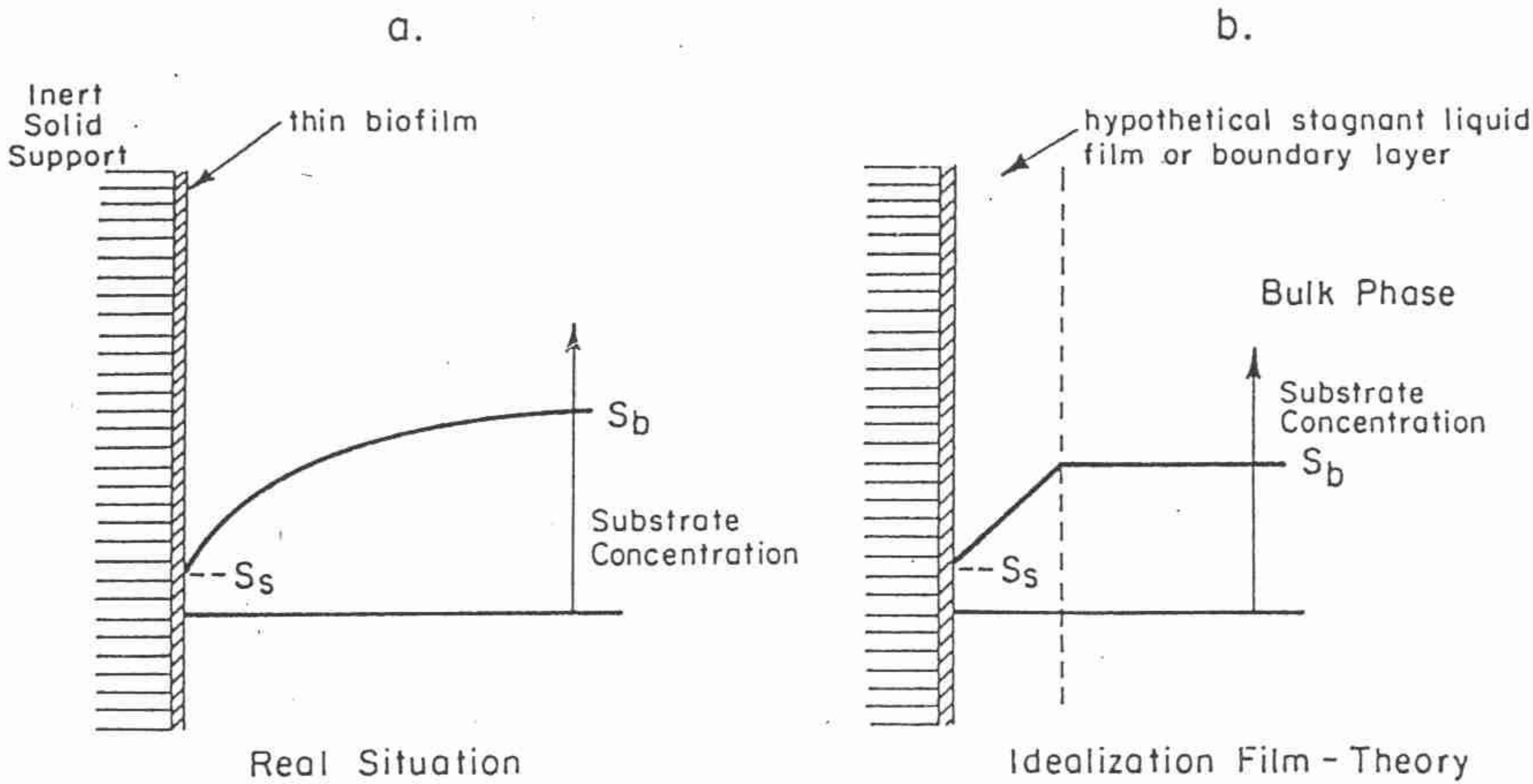


Figure 3 : Actual and idealized substrate concentration profiles for reaction at a surface with external mass transfer resistance.

- Several correlations have been suggested describing the mass transfer coefficient such as:

$$K_L = 1.3\mu \; S_c^{-1/2} \, Re^{-1/2}$$

or

$$K = 0.817\mu \; S_c^{-2/3} \, Re^{-1/2}$$

where:

μ = viscosity of fluid

S_c = Schmidt number (μ /Pd)

Re = Reynolds number

Reaction at the Surface of the biofilm

The rate of consumption of substrate at the surface of the biofilm is given by Monod kinetics:

$$-r_s = \frac{q_m S_s}{(K_s + S_s)}$$

where:

$-r_s$ = reaction rate, mass per unit time per unit area

q_m = maximum specific substrate removal rate, mass per unit time per unit area

K_s = saturation constant, mass per unit volume

S_s = substrate concentration at the biofilm surface

Mass Transfer Within the Biofilm

Substrate transport within the biofilm occurs through the process of diffusion which is characterized by Fick’s law as the following:

$$N_s = -D\,(ds/dx)$$

where:

D = diffusion coefficient, area per unit time

ds/dx = concentration gradient

Diffusion within the film:

$$N_s = -D_e\,(ds/dx)$$

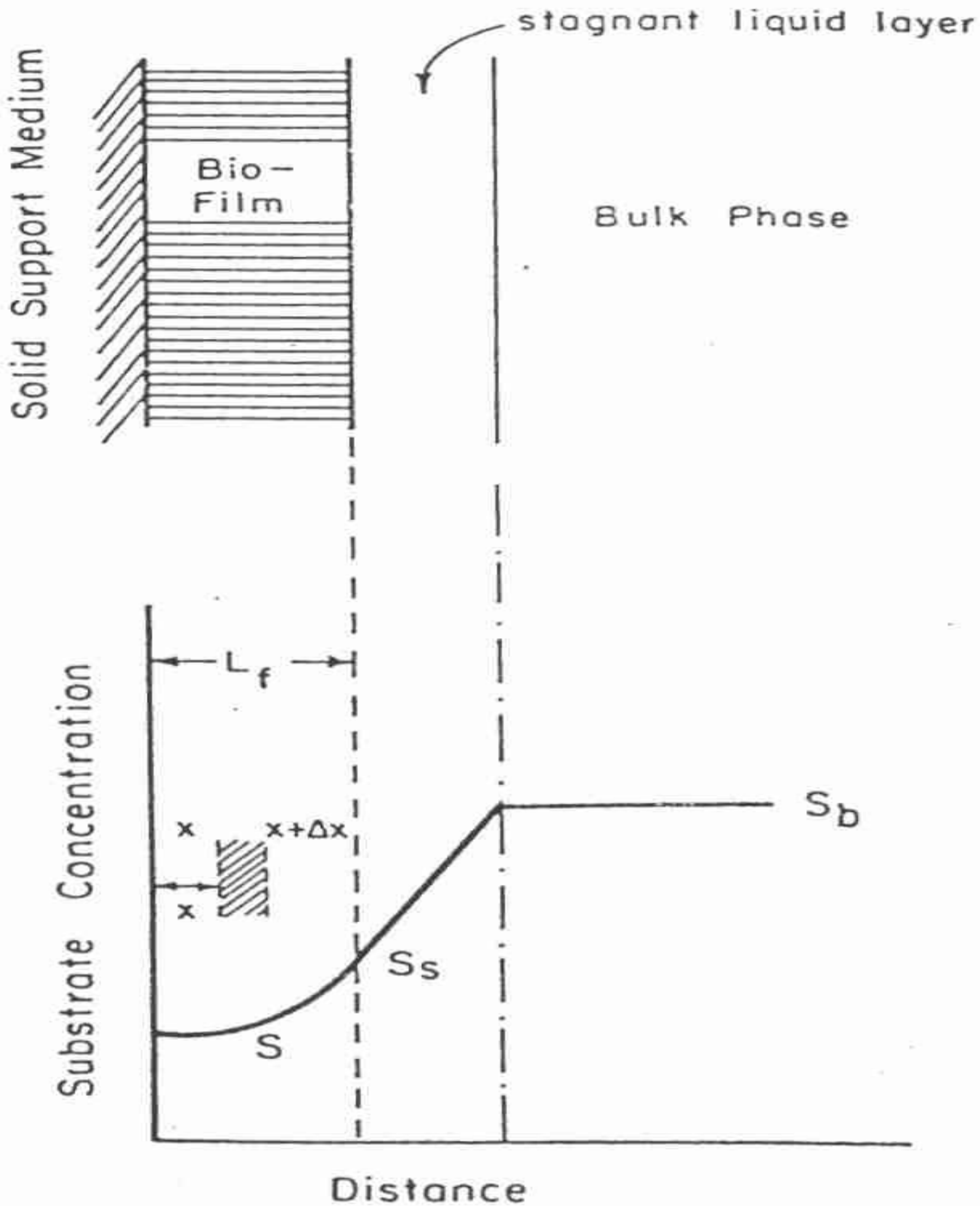


Figure 5: Overall Model

Biological Biofilm Systems

- Types of biofilm systems
  - Fixed-medium systems
    - Trickling filters
    - Packed bed reactors
  - Moving-medium systems
    - Rotating biological contactors
    - Fluidized bed reactors

Trickling Filters

Trickling filters consists of three major components; filter media, distribution system, and underdrain system.

Filter Media

- The filter media provide the surface and voids
- Should have the following characteristics:
  - Provide large surface area
  - Allows liquid to flow in a thin sheet
  - Has sufficient void spaces
  - Biologically inert
  - Chemically stable
  - Mechanically stable

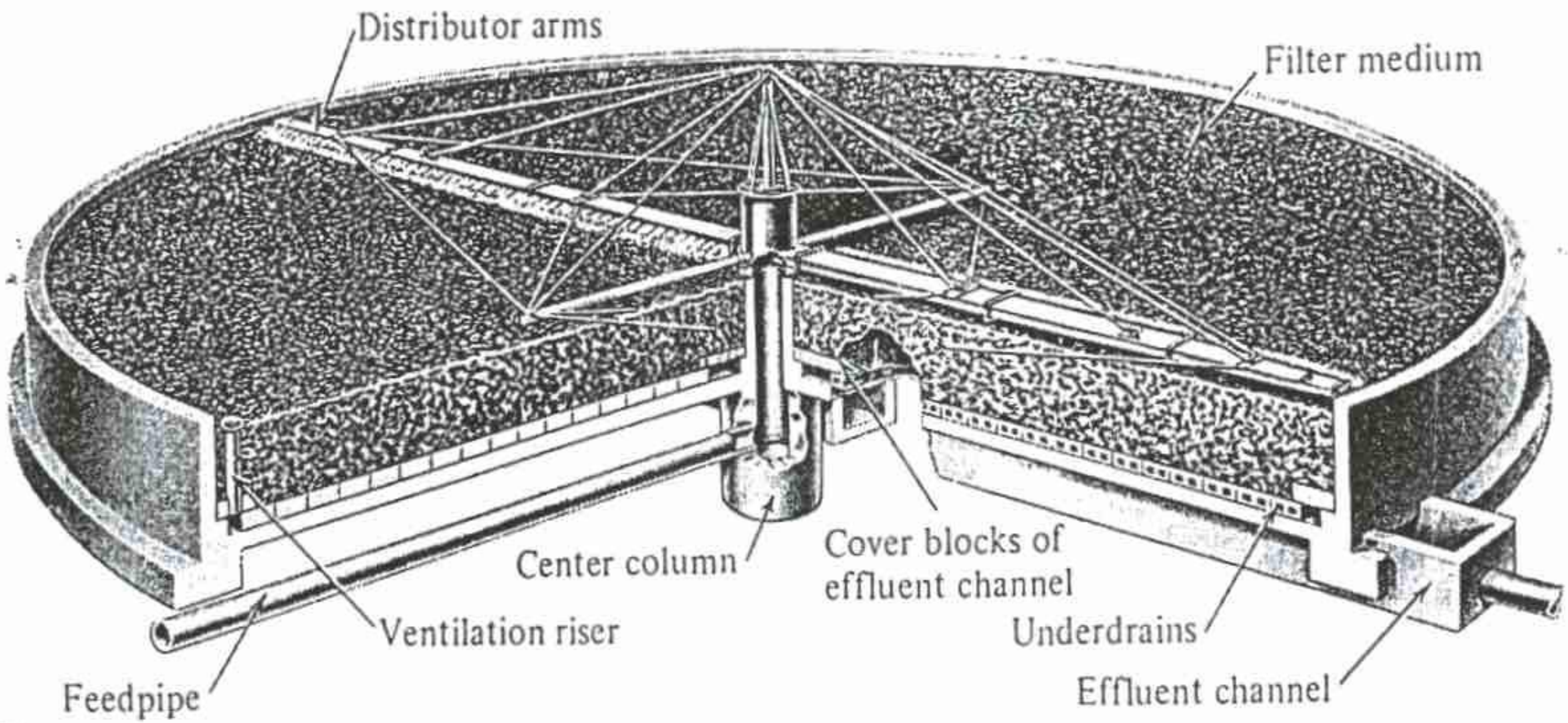


Figure 6 : Cutaway view of a trickling filter. (Courtesy of Dorr-Oliver, Inc.)

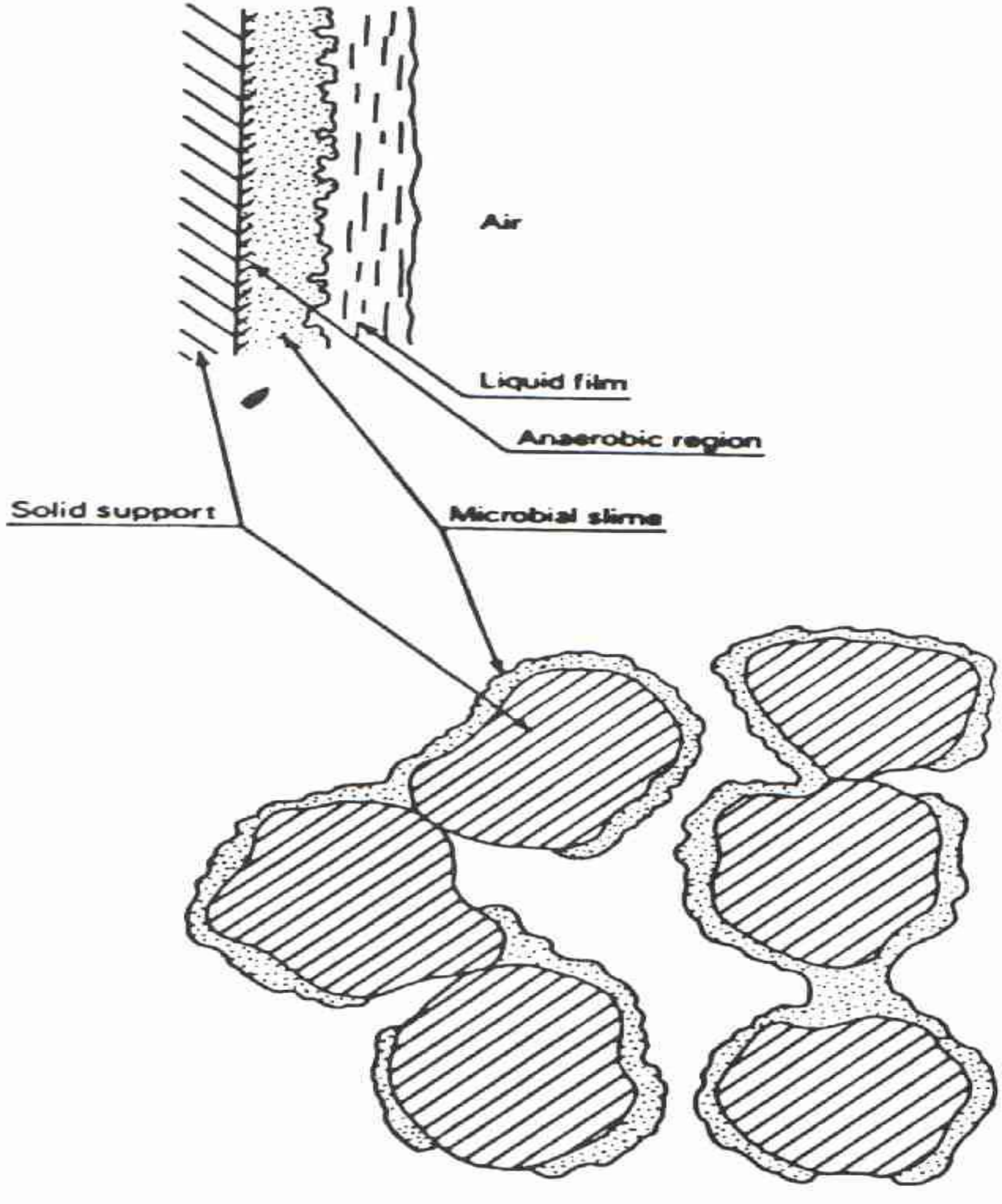
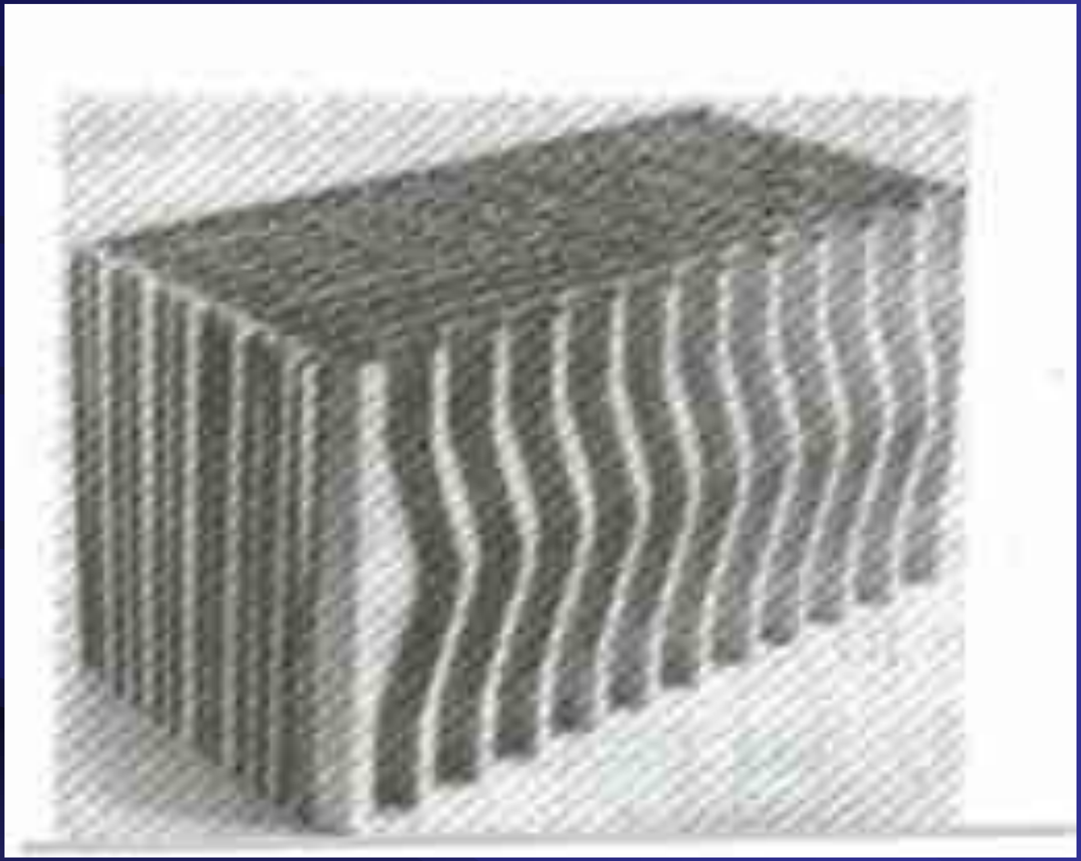


Fig. 6.1 – Microbial Slime Layer

Typical Media Used

- **Stone media**
  - usually crushed granite or lime stone
  - size ranges between 2-4 inches
  - surface area ranges from 50-98 m^2/m^3 with around 50% voids
- **Plastic media**
  - Provides large surface area
  - Provides large void spaces
  - Dumped plastic media, surface area ranges from 98-340 m^2/m^3 with void ratios of 95%
  - Modular plastic media, surface area ranges from 81-195 m^2/m^3



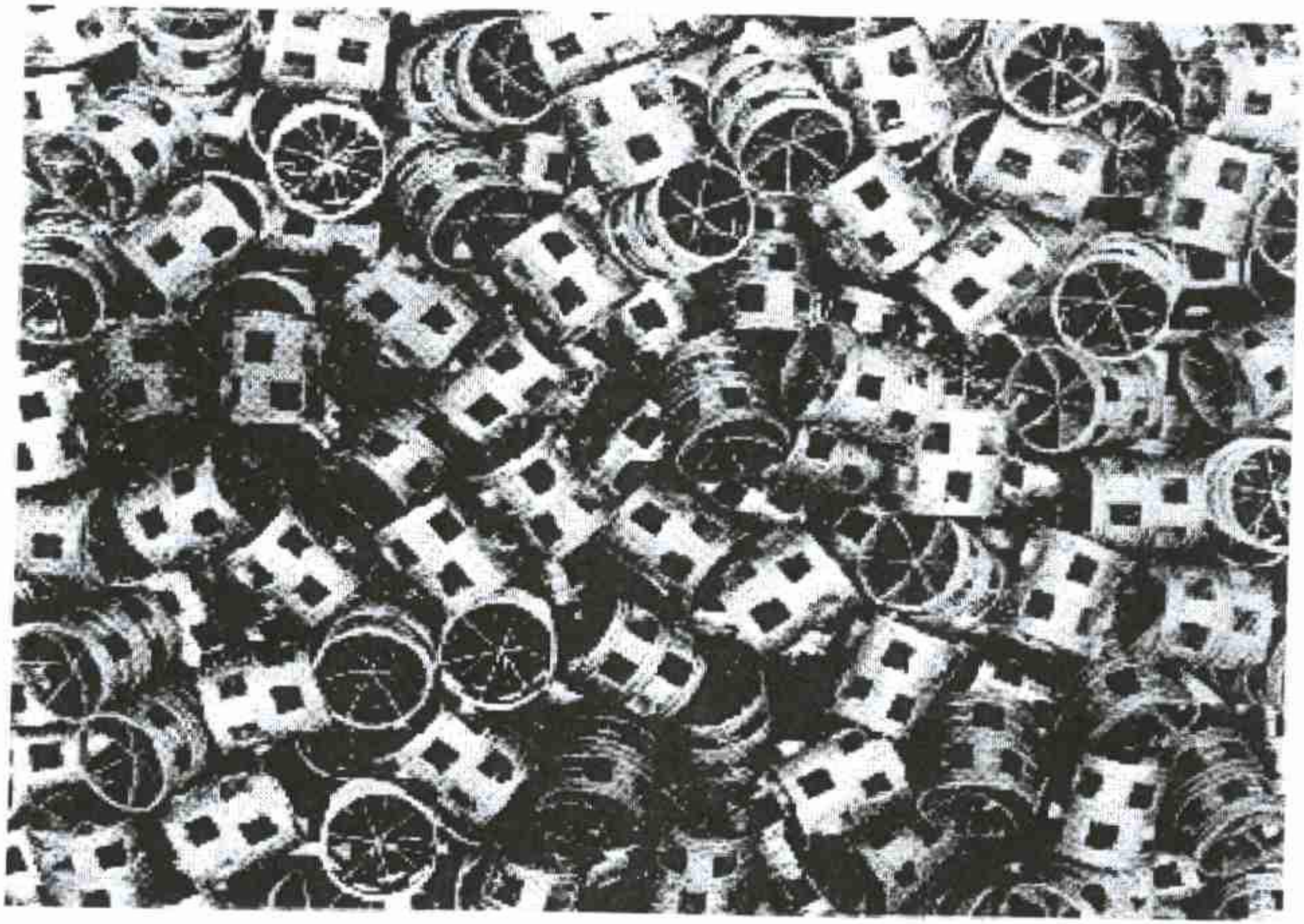


Figure 8: Dumped Plastic Media

- **Distribution system**
  - Provides uniform hydraulic loading on the filter surface
  - Rotational speed is usually 1 rev/10 min
- **Underdrain system**
  - Supports the media
  - Collects the effluent
  - Permits circulation of air through the bed
  - Made of vitrified clay (for stone media) or simple metal gratings (for plastic media)
- **Configuration**
  - Trickling filters can be employed as a single unit, units in series, or units in parallel

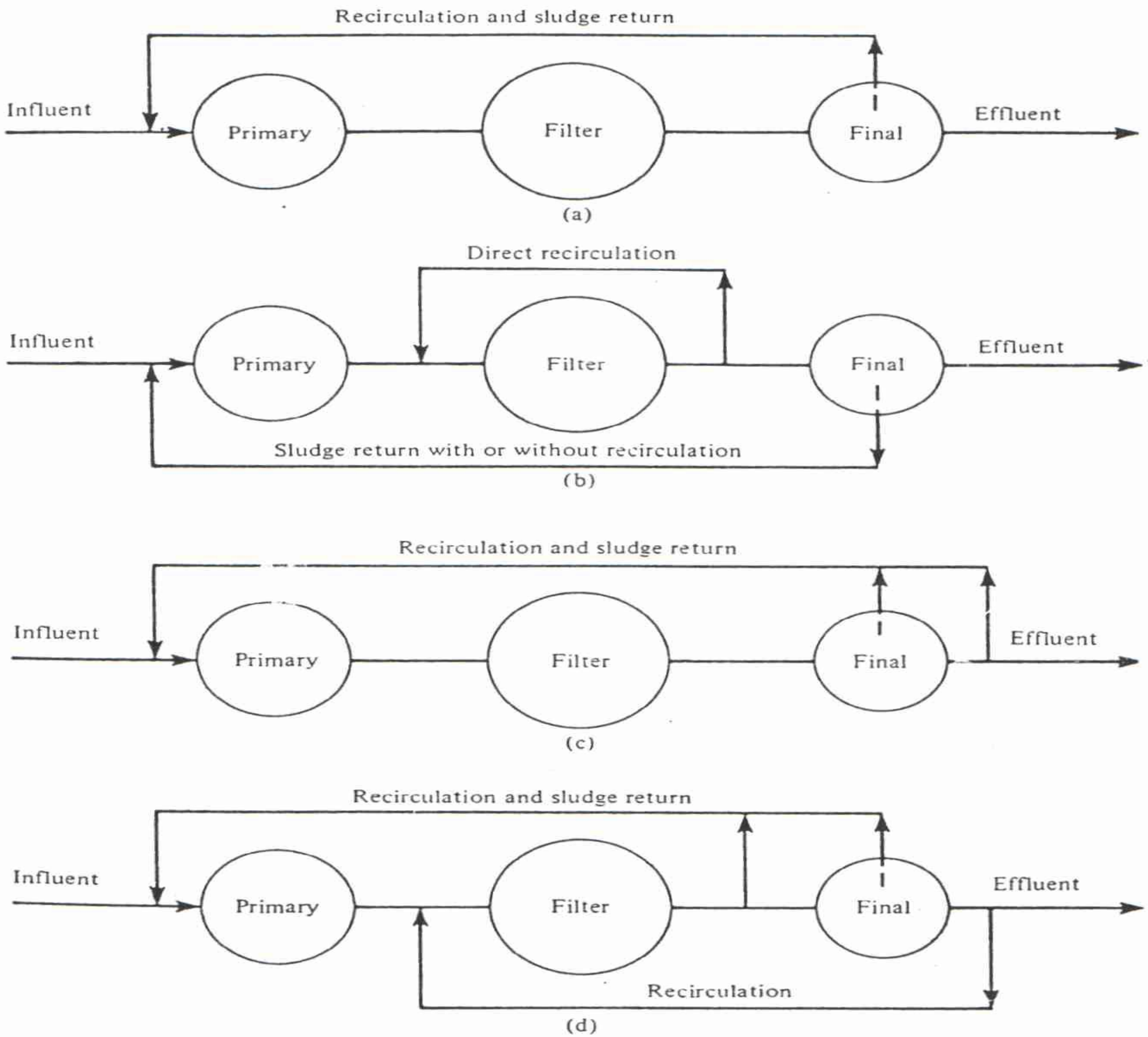


Figure 10 : Typical recirculation patterns for single-stage high-rate trickling filters. (a) Recirculation with sludge return. (b) Direct recirculation around filter. (c) Recirculation of plant effluent. (d) Dual recirculation.

- **Filter design parameters**
  - **Hydraulic Loading**
    - **Flow per unit area (m^3/day.m^2)**
    - **Upper and lower limits should be considered**
    - **Lower limit to wet all of the media**

(for plastic media limit is higher than stone media)

- **higher limit to prevent flooding of filter bed**

– Organic loading

- Is the mass application rate of organic matter per unit volume of reactor (lb BOD/day-1000ft^3)
- Higher organic loading leads to excessive growth of microorganisms
- Recirculation is used to increase the hydraulic loading while keeping organic loading constant

- **Advantages:**
  - Ideal for remote sites or small communities due to their simplicity and ease of operation
  - Can handle shock loading due to the large mass of microorganisms present in the filter and the nature of the biofilm
  - Produce dense sludge that can be easily removed by settling

- **Disadvantages:**
  - There is no control on the effluent quality in response to change in flow rate, organic concentration, and temperature
  - Breeding of flies and other insects in the summer months creates a nuisance condition in the vicinity

Fluidized Bed Systems

- **Description:**
  - Fluidized bed systems are a combination of attached-growth and suspended-growth systems
  - Bed media consists of small particles usually sand or granular activated carbon. Also, glass particles and fabricated media can be used
  - The bed packing material is kept in a suspension by an upward flow of influent wastewater
  - The effluent is discharged into a settling tank to separate biomass escaping in the effluent

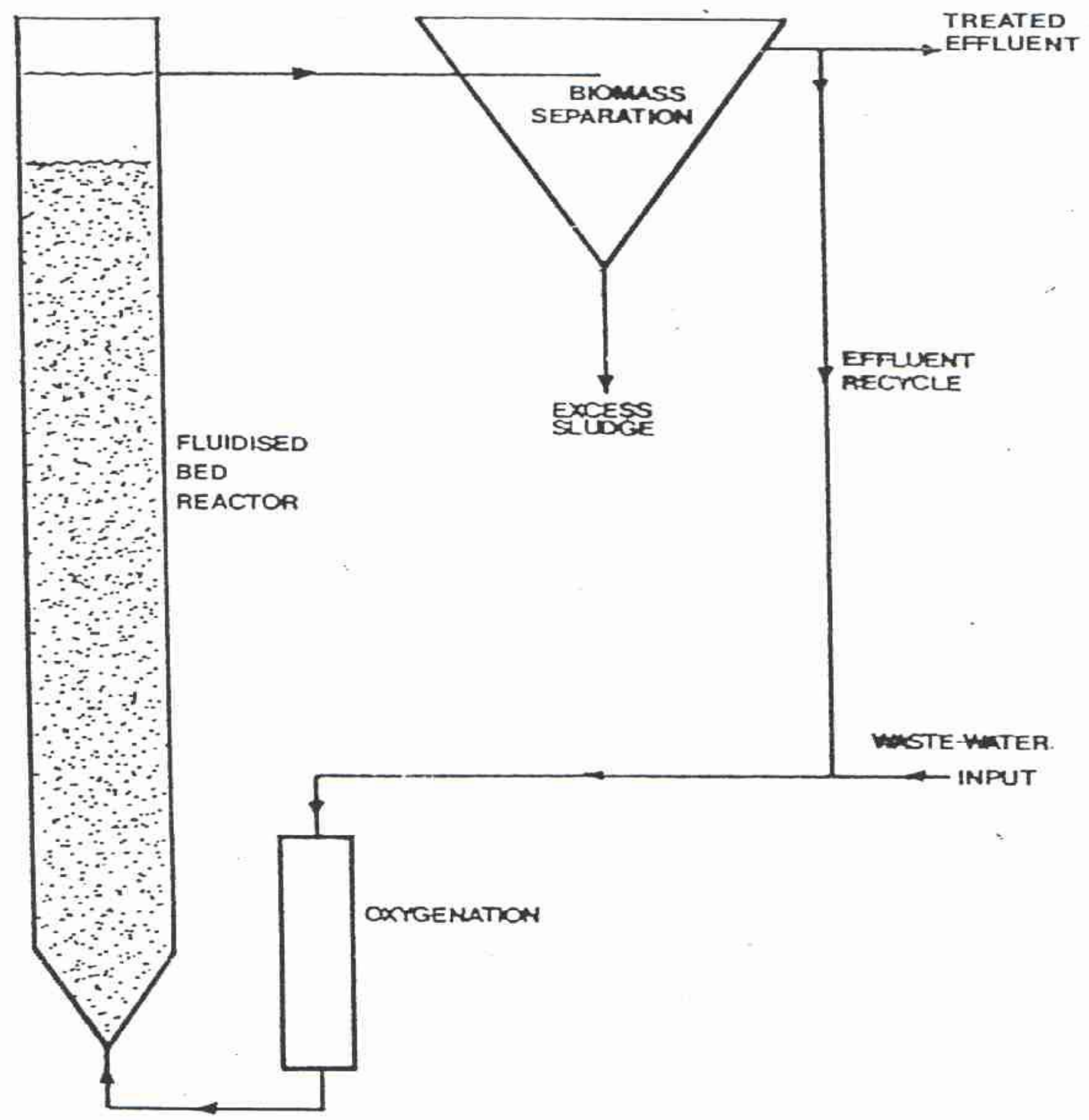


Fig. 11: – Fluidised-bed reactor scheme.

- **Principles of the Process:**
  - Liquid is passed upwards through a bed of solid particles
  - As the liquid velocity is increased, the bed expands
  - The particles separate and become free to more relative to each other
  - The liquid velocity required to achieve this effect depends on the relative densities of the liquid and the particles, as well as the size and shape of the particles

- **Advantages:**
  - Eliminate problems of clogging
  - A very large surface area is available for the growth of microorganisms
  - Small compact systems
  - Because the microorganisms are attached to the solid particles, wash-out of microorganisms are eliminated
  - Eliminate the need to recycle microorganisms back to the reactor as the case of activated sludge systems
  - Eliminates flow short-circuiting
  - Efficient mass transport

- **Disadvantages:**
  - **Requires high degree of control**
  - **Large accumulations of biological film on the surface of the particles can lead to aggregation of particles which would adversely affect system performance**

Packed-bed Systems

- **Submerged upflow reactor packed with synthetic media**
- **Operated under anaerobic conditions**
- **Recycle is desirable to dilute influent**

- **<u>Media used</u>:**
  - **Sand particles**
  - **Plastic media**
  - **Aluminum oxide particles**

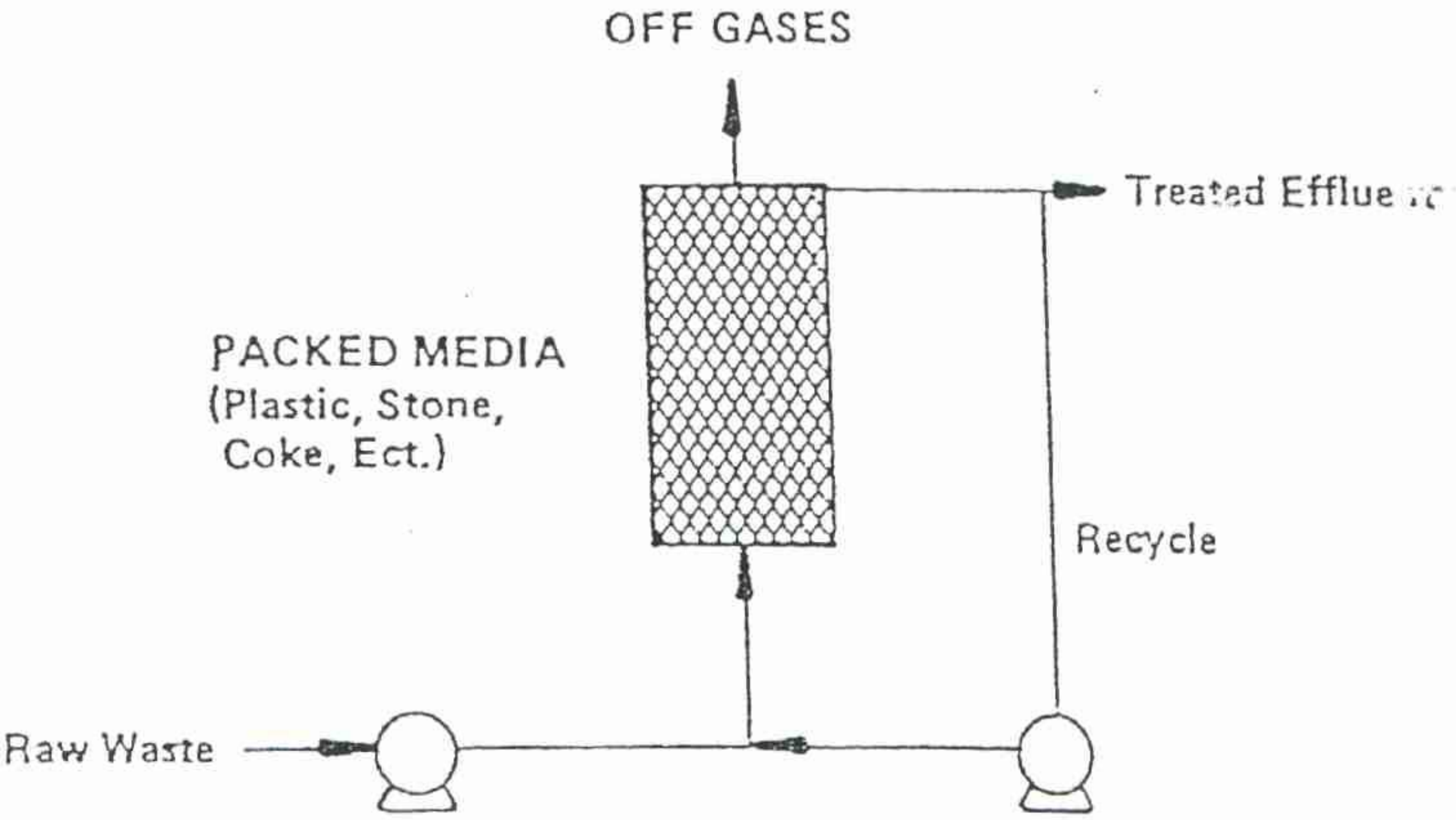


Figure 13: Schematic Diagram of Packed and Reactor

- **Advantages:**
  - Cell yield is low
  - No oxygen is required
  - Production of energy source (CH_4)
  - Low nutrient requirements

- **Disadvantages:**
  - Low growth rates
  - Sensitivity to pH changes
  - Susceptibility to toxicity and inhibition

Summary

- Application of the process has great potential
- Robust process in comparison with other biological processes
- Room for research is open

Thank You