

# ADVANCED WASTEWATER TREATMENT TECHNOLOGIES



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Prepared By:

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*The document is intended to provide guidance on “Advanced Wastewater Treatment Technologies” measures at ETP, CETP as well as STP to improve treated water quality by advanced treatment.*

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**Team for Compilation:**

**Dr. Bharat Jain**, Member Secretary, GCPC & Coordinator, ENVIS

**Mr. P.R. Rathod**, Programme Officer, ENVIS

**Mr. Sumit Patel**, Assistant Project Engineer, GCPC

**Ms. Disha Bhavsar**, Assistant Project Engineer, GCPC

**Ms. Priyanka Joshi**, Information Officer, ENVIS

**Mr. Heer Desai**, Project Assistant, GCPC-ENVIS



**Gujarat Cleaner Production Centre – ENVIS Centre**

3<sup>rd</sup> Floor, Block No. 11&12

Udhyog Bhavan, Sector-11

Gandhinagar, Gujarat-382017

(India)

Tel: +91 79 23244147

Email: [gcpc11@yahoo.com](mailto:gcpc11@yahoo.com), [gcpc-env@nic.in](mailto:gcpc-env@nic.in)

Website: [gcpcenvis.nic.in](http://gcpcenvis.nic.in), [gcpcgujarat.org.in](http://gcpcgujarat.org.in)

## **About us**

*Gujarat Cleaner Production Centre (GCPC) has been established in the year 1998 by the Department of Industries and Mines, Government of Gujarat with technical support of United Nations Industrial Development Organization (UNIDO). GCPC acts as an environmental advisor of Gujarat Industrial Development Corporation (GIDC), Government of Gujarat to solve environmental problems faced by SMEs at GIDC Industrial Estates. GCPC is actively engaged in promotion of Cleaner Production (CP) and Clean Technology (CT) through various activities such as organizing orientation and awareness programmes and conducting cleaner production assessment projects across the state.*

*GCPC is a regular member of RECPnet – The Global Network on Resource Efficient and Cleaner Production of UNIDO and CTCN – Climate Technology Centre and Network, a working arm of UNFCCC – The United Nations Framework Convention on Climate Change.*

*GCPC is acting as an Environmental Information System (ENVIS) Centre for Ministry of Environment, Forest and Climate Change, Government of India since 2005, with objective to disseminate and promote the theme of 'cleaner production and clean technology' and other environmental practices across industries, students, academicians, researchers to create sustainable development in the state of Gujarat.*

*GCPC has played active role in framing Gujarat Industrial Policy, 2009 and 2015 and many financial assistance schemes, pertaining to Cleaner Production and Clean Technology in the state of Gujarat.*

*GCPC has so far conducted more than 200 orientation programmes in various academic institution and industries associations. The centre has successfully completed more than 100 Cleaner Production Demonstration Projects in various industrial sectors such as Textile, Dairy, Pulp and Paper, Chemical, Petrochemical, Pharmaceutical, Fish Processing, Ceramic and Glass etc.*

## Foreword



*Gujarat is proactive towards wastewater treatment. Presently 37 CETPs are in the state, out of which 33 CETPs are operational and 4 are either proposed or at commissioning/construction stage. Out of 33 operating CETPs 9 Nos. are exclusively for treating effluent generated from textile sectors and 2 for electroplating sector while the rest are for chemical and other allied industries. Total Treatment Capacity of operational CETPs is 575.535MLD proposed CETPs will be & 150.4 MLD.*

*In each industrial estate of Gujarat, estate wise or sector wise wastewater treatment facilities are designed. More than 20 wastewater treatment facilities are based on Traditional or Conventional wastewater treatment which includes Mechanical methods (Flotation, clarification (settlement/thickening) or filtration), Biological methods (Aerobic / anaerobic methods, (primary and secondary clarification)) and Chemical methods (Precipitation + (clarification or flotation). Most of CETPs receives mix effluent (cocktail). Therefore these treatment facilities are not able to achieve the discharge norms. If treated effluent from these plants discharged into a stream with low flow can cause damage to aquatic life by reducing the dissolved oxygen content. In addition the secondary effluent contains significant amounts of plant nutrients, Suspended solids and dissolved solids.*

*Due to stringent regulations for disposal of wastewater coupled with water stress and scarcity in certain areas there is a great need of **advanced wastewater treatment** with parameter wise wastewater stream segregation as segregated wastewater stream can be easily treated and it may have potential to achieve discharge norms to satisfy any of the several specific goals. Gujarat Cleaner Production Centre (GCPC) promotes the concept of CP (Cleaner Production) & CT (Clean Technology). As a part of it this publication introduces the concept of Advanced wastewater treatment including its working principle, procedure, implementation, advantages,*

*disadvantages, application, case study etc... and removal of (1) suspended solids (2) BOD (3) plant nutrients (4) dissolved solids and (5) toxic substances. These treatment technologies may be introduced at any stage of the total treatment process as in the case of industrial waterways or may be used for complete removal of pollutants after secondary treatment.*

*Hopefully this publication will be useful for all the stakeholders of wastewater treatment facility.*



**Dr. Bharat Jain**

Member Secretary, GCPC & Coordinator, ENVIS  
Gujarat Cleaner Production Centre



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## Abbreviations

<b><i>ETP</i></b>	<i>Effluent treatment plant</i>
<b><i>CETP</i></b>	<i>Common effluent treatment plant</i>
<b><i>TDS</i></b>	<i>Total dissolved solid</i>
<b><i>TSS</i></b>	<i>Total suspended solid</i>
<b><i>VSS</i></b>	<i>Volatile suspended solid</i>
<b><i>BOD</i></b>	<i>Biochemical oxygen demand</i>
<b><i>COD</i></b>	<i>Chemical oxygen demand</i>
<b><i>ASP</i></b>	<i>Activated sludge process</i>
<b><i>SRT</i></b>	<i>sludge retention time</i>
<b><i>SOR</i></b>	<i>sludge overflow rate</i>
<b><i>WOR</i></b>	<i>weir overflow rate</i>
<b><i>MLD</i></b>	<i>Million liter per day</i>
<b><i>MLSS</i></b>	<i>Mixed liquor suspended solid</i>
<b><i>MLVSS</i></b>	<i>Mixed liquor volatile suspended solid</i>
<b><i>TS</i></b>	<i>Total solids</i>
<b><i>MoEFCC</i></b>	<i>Ministry of Environment, Forest &amp; Climate Change</i>
<b><i>CAPEX</i></b>	<i>Capital Expenditure</i>
<b><i>OPEX</i></b>	<i>Operational Expenditure</i>
<b><i>SAD</i></b>	<i>Specific Aeration Demand</i>
<b><i>DAF</i></b>	<i>Dissolved Air Flootation</i>
<b><i>SMP</i></b>	<i>Soluble Microbial Product</i>
<b><i>IMBR</i></b>	<i>Immersed Membrane Bioreactor</i>
<b><i>SMBR</i></b>	<i>Submerged Membrane Bioreactor</i>
<b><i>TPH</i></b>	<i>Total Petroleum Hydrocarbons</i>

## INTRODUCTION

### WASTEWATER

*Wastewater, also written as waste water, is any water that has been adversely affected in quality by anthropogenic influence. Wastewater can originate from a combination of domestic, industrial, commercial or agricultural activities, surface runoff or storm water, and from sewer inflow or infiltration. Municipal wastewater (also called sewage) is usually conveyed in a combined sewer or sanitary sewer, and treated at a wastewater treatment plant. Treated wastewater is discharged into receiving water via an effluent pipe. Wastewaters generated in areas without access to centralized sewer systems rely on on-site wastewater systems. These typically comprise a septic tank, drain field, and optionally an on-site treatment unit. The management of wastewater belongs to the overarching term sanitation, just like the management of human excreta, solid waste and storm water (drainage). Industrial wastewater is defined as any wastewater generated from any manufacturing, processing, institutional, commercial, or agricultural operation, or any operation that discharges other than domestic or sanitary wastewater.*

### WASTEWATER GENERATION

*Rapid industrialization has resulted in the generation of huge quantity of wastewater from industrial sectors such as sugar, pulp and paper, fruit and food processing, sago / starch, distilleries, dairies, tanneries, slaughterhouses, poultries, etc. Despite requirements for pollution control measures, these wastewater are generally dumped on land or discharged into water bodies, without adequate treatment, and thus become a large source of environmental pollution and health hazard. Wastewater management in India has become an extremely important area of focus due to increasing health awareness and population pressure. Despite the wastewater sector witnessing major growth in the last decade due to increasing government support and private participation, the scale of the problem remains enormous. For instance, it is estimated that less than 20% of domestic and 60% of industrial wastewater is treated. Metros and large cities (more than 100,000 inhabitants) are treating only about 29.2% of their wastewater; smaller cities treat only 3.7% of their wastewater. Industrial wastewater includes industrial effluents (with or without pre-treatment), but sometimes also cooling water from energy production and*



mining water. The slight improvement in wastewater quantity is mostly based on reduction in the production process, and not always because of improvements or constructions of effective treatment facilities.<sup>33</sup>

## INDUSTRIALIZATION IN GUJARAT

Gujarat is one of India's most industrialized states, Gujarat maintains a variety of industries, the principal ones being general and electrical engineering and the manufacture of textiles, vegetable oils, chemicals, soda ash, and cement. New industries include the production of fertilizers and petrochemicals. Major resources produced by the state include cotton, peanuts, dates, sugarcane, and petrol. The state is rich in calcite, gypsum, manganese, lignite, bauxite, limestone, agate, feldspar and quartz sand and successful mining of these minerals is done in their specified areas. Gujarat produces about 91% of India's required amount of soda ash and gives the country about 66% of its national requirement of salt. Chemical Industries in Gujarat count for more than 35% of Indian Chemicals production. It is one of India's most prosperous states, having a per-capita GDP significantly above India's average. Kalol Khambhat and Ankaleshwar are today known for their oil and natural gas production. 'Dhuvaran' has a thermal power station, which uses coal, oil and gas. The Tarapur nuclear station in Maharashtra supplies the remaining power. Also on the Gulf of Khambhat, 50 kilometers southeast of Bhavnagar, is the Alang Ship Recycling Yard (the world's largest). General Motors produces the 'Astra' car at Halol near Vadodara. Jalalpur is a large town of Gujarat, where several small and large textile industrial units have been established. Surat, a city by the Gulf of Khambhat, is a hub of the global diamond trade.

Ahmedabad, Ankleshwar and Vapi are the hub of Chemical Industries in the state, having number of manufacturing units (private as well as state owned) manufacturing Dyes, Especially chemicals, Agro Chemicals, Pesticides, Pigments, Colors etc. Rajkot city is the hub of Engineering manufacturing and has many manufacturing companies manufacturing Auto Components, Auto Engines, CNC machines, forging & casting parts etc. The state operating companies like GNFC, GSPC, GSFC, and GMDC are a few among flagship companies of the state. Gujarat achieved as much as 35% of augmentation in its power generation capacity during the period 1995–96 and 2000–01. The producers (IPPs) have contributed significantly in this addition. As a matter of fact Gujarat is one of the first few states in India to have encouraged private sector investment and is already in operation. In addition the liquid cargo (chemicals) handling port at Dahej is also set up in joint sector and made operational. At an investor's

summit entitled Vibrant Gujarat arranged between January 10, 2007 to January 13, 2007, at Science City, Ahmedabad, the state government signed 104 Memorandum of Understandings for Special Economic Zones totaling worth Rs 2.5 lakh crore. However, most of the investment was from domestic industry.

**Table 1. STATUS OF CETP IN GUJARAT**

<i>Parameters</i>	<i>Operational</i>	<i>Proposed</i>
<i>Total Number of CETPs in Gujarat (as on March 2015)</i>	<i>33</i>	<i>4</i>
<i>Total Treatment Capacity</i>	<i>575.535 MLD</i>	<i>150.4 MLD</i>

- *Total Treatment Capacity of 575.535MLD (operational) & 150.4 (proposed)*
- *Treatment Capacity Range – Max. 100 MLD to Min. 0.01 MLD.<sup>1</sup>*

### **CETP Business Model**

#### ***Scope of Central assistance for CETPs:***

*The Central assistance will be available for:*

- *Establishment of new CETPs in an industrial estate or a cluster of SSIs.*
- *Up gradation/modernization proposal for CETPs earlier financed through the MoEF shall be considered for one time funding. However, there has to be adequate justification for the same and the time interval between the commissioning of the existing CETP and the submission of proposal for up gradation/ modernization to the Central Government should not be less than 7 years.*

*The zone of eligibility of CETPs to be considered for support under the scheme should exclude integrated textile parks and high growth clusters on the priority list of the IIUS scheme of DIPP for the XII FYP.*

*The project cost may include:*

- *Plant and Machinery for Primary, Secondary and Tertiary treatment.*

- On-site laboratory with standard set of instruments.
- Zero Liquid Discharge (ZLD) and related technologies.

*Large and Medium scale industries, other than those belonging to the 17 categories of heavily polluting industries, may join the CETP after the primary treatment or as considered necessary by the concerned SPCB for the purpose of hydraulic load and for the techno-economic viability of the CETP. However, it has to be ensured that the CETP primarily services the effluent discharged by the SSIs which shall contribute at least 50% of the total effluent load at the inlet of the CETP.*

***Pattern of financial assistance:***

*The financial assistance for a CETP project shall be as follows, subject to the conditions mentioned below:*

- *The Central assistance (subsidy) will be restricted to 50% of the total project cost. The modified ratio proposed in respect of Central share: State share: Project Proponent's share will be 50:25:25. Out of the proponent's share, atleast 40% of contribution has to be from the proponent and balance 60% is to be raised through loan to the proponent from Banks/Financial Institutions.*
- *Central subsidy shall be released subject to two conditions: One, the State subsidy is made available to the CETP project; two, Bank guarantee for an equivalent amount has been procured by the SPCB/PCC.*
- *The Central assistance will be provided only to meet capital costs towards the items mentioned in para no. 3 of Scope of Central assistance for CETPs*
- *No assistance will be provided for meeting recurring or operation and maintenance costs.*
- *The Central Government shall not have any liability towards time and cost over runs.*
- *There is no provision for retrospective funding.*
- *Central assistance cannot be used as seed money for the CETP*

*For CETPs involving primary / secondary / tertiary treatment, financial assistance would be provided by GOI to the tune of 50% of maximum Rs. 1.50 crore / MLD capacity, subject to a ceiling of Central assistance of Rs. 15 crore per CETP.*

*For CETPs involving primary / secondary / tertiary treatment and ZLD treatment, financial assistance would be provided by GOI to the tune of 50% of maximum Rs. 4.50 crore / MLD capacity, subject to a ceiling of Central assistance of Rs. 20 crore per CETP.<sup>2</sup>*

## **EXISTING TREATMENT TECHNOLOGIES**

### **PRELIMINARY**

- (1) Screening*
- (2) Grit chamber*

### **PRIMARY**

*The primary treatment involves various physical-chemical processes:*

- (1) Equalization*
- (2) Coagulation and Flocculation*
- (3) Sedimentation*
- (4) Dissolved Air Floatation*
- (5) Clarification*

### **Chemical Treatment Processes**

- (1) Neutralization*
- (2) Precipitation*

### **Secondary treatment**

- (1) Activated sludge process*
- (2) Biological filters*
  - *Trickling Filters*
  - *Rotating Biological Contractor (RBC)*

### *(3) Anaerobic Treatment Systems*

- *Upflow Anaerobic Sludge Blanket Reactor (UASB)*

### ***Tertiary Treatment***

#### *(1) Granular Media Filtration*

- *Sand filters*
- *Dual or multimedia filtration consists of two or more media*

#### *(2) Membrane Filtration*

#### *(3) Reverse Osmosis Systems*

#### *(4) Ion Exchange*

#### *(5) Activated carbon*

#### *(6) Ultraviolet (UV) Disinfection*

### ***Why we need Advanced Treatment***

*The use of conventional water and wastewater treatment processes becomes increasingly challenged with the identification of more and more contaminants, rapid growth of population and industrial activities, and diminishing availability of water resources because, the effluent from a typical secondary treatment plant still contains 20-40 mg/L BOD which may be objectionable in some streams. Suspended solids, in addition to contributing to BOD, may settle on the stream bed and inhibit certain forms of aquatic life. The BOD if discharged into a stream with low flow can cause damage to aquatic life by reducing the dissolved oxygen content. In addition the secondary effluent contains significant amounts of plant nutrients and dissolved solids. If the waste water is of industrial origin, it may also contain traces of organic chemicals, heavy metals and other contaminants. Different methods are used in advanced waste treatment to satisfy any of the several specific goals, which include the removal of (1) suspended solids (2) BOD (3) plant nutrients (4) dissolved solids and (5) toxic substances.*

*These technologies provide alternatives for better protection of public health and the environment and thus are reviewed in this paper. The emphasis is placed on their basic principles, main applications, and*

*new developments. Advantages and disadvantages of these technologies are compared to highlight their current limitations and future research needs. It can be concluded that, along with the growing knowledge and the advances in manufacturing industry, the applications of these technologies will be increased at an unprecedented scale.*

*These treatment technologies may be introduced at any stage of the total treatment process as in the case of industrial waterways or may be used for complete removal of pollutants after secondary treatment.*



## **(I) Automated Chemostat Treatment (ACT)**

### **Description**

*Automated Chemostat Treatment is a novel method in the treatment of sludge. This technology is flexible and easy to integrate, fully automated, controllable and significantly more efficient than current practices. The scientific concepts behind ACT are the use of an appropriate bacterial cocktail for a given type of polluted water and an innovative chamostat. The process is maintained in a balanced state of bacterial growth and organic compound degradation. Because of the low concentration of bacterial cells, no aggregates are formed, and each bacterium acts as a single cell which increases the surface available for the process and enables biodegradation at a much higher efficiency. The results are a virtually sludge-free output of water which can be returned directly into the environment or processed further. ACT reduces hydrocarbons, TOC, COD, and suspended solids from greasy and oily waters, leaving effluents well below industry regulation levels. Based on a water sample from the refinery, ACT determines the most effective solution for treating the specific refinery issues. The hydraulic age and the bacterial age become equal, requiring a lower density of single cell bacteria. The ACT operates as a continuous flow reactor without using activated sludge. The bioreactor can thus be applied on site while using available infrastructure with high flexibility for modulation of the process saving dramatically in operational and maintenance costs.<sup>3</sup>*

### **Implementation**

*The modular approach provided by this solution allows for on-site implementation leveraging existing infrastructure. As such, when treating stripped sour water streams, the system can be integrated in a complementary fashion with the refinery main-stream process. Alternatively, it can be implemented as a completely separate process. In the first option, stripped sour water passes through the API and DAF units and then enters the ACT bioreactor. Following the biological treatment, the treated stripped sour water can be returned to the main bioreactor for further biodegradation, filtration and discharge. In the latter option, after undergoing API and DAF treatments, the stripped sour water can be biologically treated in the ACT bioreactor, filtered, and then directly discharged to the environment. The complete separation of the stripped sour water from the main stream is advantageous in two regards. Firstly, such*

water, after proper treatment, can be recycled for additional usages in various refinery processes. Secondly, the total organic load in the main-stream is significantly decreased, allowing for higher treatment capacity and efficiency.

### ***Full Control from Any Point for Every Point:***

The fully automated system is comprised of a variety of on line sensors which feed the control unit information on various parameters such as: TPH, nitrogen, dissolved oxygen, TOC and temperature. The controller ensures to maintain optimum process balance between the flow rate, bacterial growth, additives and organic compound degradation.<sup>5</sup>

### ***ACT System Key Features***

- Customized for optimal cost-effective performance
- Increased capacity to prevent shortfalls during peak time processing
- Fully-automated process
- Process stability maintained, even during inlet fluctuation

***Table 1.2 Water Quality Specifications with ACT Technology***

<b><i>Wastewater Parameter</i></b>	<b><i>% Reduction</i></b>	<b><i>Treatment Range (ppm)</i></b>
<b><i>TPH</i></b>	99	5-300
<b><i>COD</i></b>	90	400-4000
<b><i>TOC</i></b>	90	100-1000
<b><i>TSS</i></b>	90	50-200
<b><i>Phenol</i></b>	99	2-35
<b><i>T-Nitrogen</i></b>	90	50-200
<b><i>BTEX</i></b>	99	10-200

## **ACT Benefits for Refineries**

- *Eliminates the need to reactivate bio-sludge*
- *Creates a more streamlined and efficient process by eliminating many complex operations*
- *Reduces costs by as much as 50%*
- *Reduces sludge generation and handling significantly as well as corresponding chemical usage.<sup>6</sup>*

## **Advantages**

*ACT simplifies the process by reducing bio sludge and chemical usage as well as reducing black sludge creation. ACT's flexibility and modularity enables to handle low and high capacities and contamination, to be used for fresh and salt water as well as to be easy modify and Increase capacities. Output is virtually sludge-free, meeting strictest disposal standards. This trailblazing “green” process is easy to modify and can be used in various sites, including oil refineries, oil storage farms, drilling sites, marine ports, contaminated reservoirs and storage tanks.*

## **Application**

- *ACT technology directly addresses the three main drawbacks of conventional water treatments in refineries: Firstly, there is no longer any need to reactivate biosludge.*
- *ACT eliminates the requirement of DAF process and save time.*
- *Output, which is virtually sludge-free, can be deposited directly in nature by reducing bio-sludge handing and the creation of black sludge, as well as sufficiently eliminating nitrogen.*
- *ACT's output meets the strictest disposal standards, requiring no further handling.*
- *The quality achieved by ACT can sometimes even surpass international standards such as COD<50 ppm and Oil<2ppm as typical, so that quality achievements are clearly distinctive and unprecedented.*
- *ACT offers highly effective treatment of side streams, so often the cause of catastrophes in conventional treatment processes. Side streams severely impact the mainstream, causing bottlenecks and more severe events.*
- *ACT can be implemented without adding a complete additional treatment system.*



**Figure 1.2 Automated Continuous Flow**

- Allows separation of heavily contaminated streams and increases overall productivity.
- Provides an efficient way to break down and remove oil, phenols, PAH and other organics.
- The patented process utilizes unique bioremediation technology to reduce hydrocarbons, TOC, COD and suspended solids from greasy and oily waters, leaving effluent of high quality meeting stringent industry standards.
- The bioreactor can be applied on-site (using the available infrastructure) due to its high flexibility in process modulation. This dramatically decreases operational and maintenance costs.

**Table 1.3 Conventional Bioremediation VS. ACT (Automated Chemostat Treatment)<sup>7</sup>**

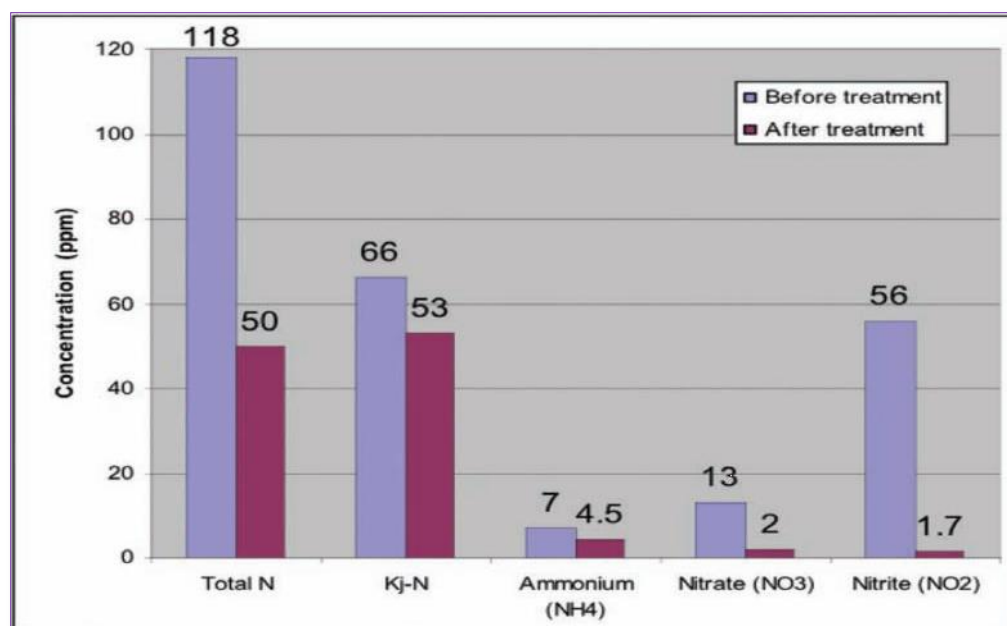
Parameter	Conventional Bio	BPC ACT
MLSS	3000 – 5000	400-500
Bacteria age	3-5 Weeks	24 Hours
F/M Ratio	Limited (0.2 – 0.4)	Very High (2-20)
Sensitivity to high COD	Very sensitive	Low sensitivity
Sludge Yield	30 – 50%	13-15%

### ***Treatment of sour water by ACT (CASE STUDY)***

A stripped sour water sample was treated using the ACT technology in a continuous mode. During the treatment process, the water was analyzed for nitrogen, phenol, solid levels, COD and TOC reduction. The water in the reactor was kept at room temperature, and at a constant DO and pH. In addition to the high carbonaceous contaminants, the treated water contained high levels of nitrogen and phenol. During the ACT process, the carbon uptake was very high. The total organic carbons (TOC) were consumed at an efficiency level of 75%. In correlation, COD was consumed at an efficiency level of 85% and the TPH was consumed at an efficiency level of 99%. In addition, the phenols were also consumed to an extremely low level of 0.1 ppm (99% reduction). The nitrogen uptake during the ACT process was particularly interesting in this project. As shown in the graph below, the biological process alone (without any filtration) reduced the total nitrogen levels to a final amount of 50 ppm, indicating that 58% of the nitrogen was consumed by the bacteria. During the bioprocess different forms of nitrogen were measured (ammonium, nitrate, nitrite, N-total).

***Table 1.1 Carbon uptake during the ACT process for a refinery stripped sour water***

<i>Parameters</i>	<i>Unit</i>	<i>Before Treatment</i>	<i>After Treatment</i>	<i>% Reduction</i>	<i>By Standard Method</i>
<b><i>COD</i></b>	<i>PPM</i>	2480	372	85	<i>Photometric EPA 410.4</i>
<b><i>TOC(NPOC)</i></b>	<i>PPM</i>	683	171	75	<i>SM 4310 B</i>
<b><i>Oil/TPH</i></b>	<i>PPM</i>	8.3	0.1	99	<i>FTRI EPA 418.1</i>
<b><i>Phenol(C<sub>6</sub>H<sub>6</sub>O)</i></b>	<i>PPM</i>	14.60	0.1	99	<i>Photometric</i>
<b><i>Turbidity</i></b>	<i>NTU</i>	545	28.60	95	<i>Photometric DIN EN 27027</i>
<b><i>TSS(105)</i></b>	<i>PPM</i>	45	103	-	<i>SM 2540 D</i>



**Figure 1.1 Biological reduction of the different nitrogen forms during the ACT process**

*It is important to note that the measurements are performed on mixed water from the bioreactor without any precipitation of the bacteria. Therefore, the difference of 68 ppm in the total-N levels before and after the ACT process, presents the fraction that was evaporated from the system, and not assimilated in the bacterial cells. The reduction of N-total is mainly derived from a decrease in the nitrite from 56 ppm to 2 ppm. This is a very interesting finding as usually, ammonia is a preferable nitrogen source over nitrite. Apparently, the unique technology of ACT resulted in a bacterial cocktail that prefers nitrite as a nitrogen source. It is commonly known that de-nitrification occurs under anaerobic conditions, which raises the question of how such de-nitrification occurred in the continuously aerated bioreactor. However, this phenomenon of N-total reduction under aerobic condition is field proven as demonstrated in this case. ACT technology for stripped sour water treatment (either prior to the activated sludge stage or as a replacement to it) will lead to reduced overloads at an over-all increased capacity, and at lower operational costs.<sup>4</sup>*



## (2) Soil Biotechnology (SBT)

### Description

Soil Bio- technology is a terrestrial system for wastewater treatment which is based on the principle of trickling filter. In this system, combination of physical processes like sedimentation, infiltration and biochemical processes are carried out to remove the suspended solids, organic and inorganic contents of the wastewater. Suitable mineral constitution, culture containing native micro-flora and bio-indicator plants are the key components of the system. It is also known as **Constructed Soil Filter (CSF)**. SBT system constructs from RCC, stone-masonry and/or soil bunds. It consists of raw water tank, bioreactor containment, treated water tank, piping and pumps. Soil Biotechnology (SBT) is an environment friendly waste processing technology that offers systems for processing of both solid organic wastes and wastewater treatment using bacteria, earthworms and mineral additives in a garden-like setup. SBT reinforces the carbon and nitrogen cycles in nature, the quality of the treated water exceeds state pollution control board standards reducing Chemical Oxygen Demand (COD).



### Purpose and Need of SBT

- A sewage management solution, due to non-availability of any civil drainage system to protect ground water resources and the nearby lakes and river, from pollution by the sewage.

- *To adopt a natural method, to avoid the side-effects which come from deploying chemicals for sewage treatment. Overall, the procedure should be eco-friendly and at the same time are highly flexible and scalable.*

### **Working Principle of SBT**

*The SBT system is an engineered ecology of soil plant system configured as a packed bed reactor with multi grade media consisting of different sizes of stone, gravel and formulated soil enriched along with micro flora and geophagus earthworm culture. Chemistry, Biology and Ecology in SBT facilitates both aerobic & anaerobic respiration, and reactions like nitrification, denitrification, acidogenesis, etc depending on the types of waste load. Organics get removed by adsorption & filtration and are biologically converted to CO<sub>2</sub> with help of indigenous soil microflora. Suspended Solids are removed in Primary Settling Unit. Dissolved Solids are removed by adsorption followed by biodegradation and uptake by green plants. Media and additives provide sites for biological transformation. Earthworm culture regulates microbial ecology. Health of green plants bio-indicate the process.*

### **Procedure**

*Soil Biotechnology harnesses the bioenergy in organic matter by integrating the elements of a productive soil ecosystem viz. soil bacteria, select earthworm and plant species and mineral nutrients. Litter pests indicate over loaded process and warrant corrective measures. Biocarbon energy contained in the waste is tapped to unlock plant nutrients from minerals, fix atmospheric nitrogen and produce metabolites to be assimilated by plants and thus prevent wasteful dissipation of the carbon energy. Presence of select aerobic bacteria and mineral additives prevent foul odor in the process. Two grades of bio-fertilizer can be harvested from Life Link's Soil Biotechnology process, namely, Fertilizer Grade and Culture Grade, depending on the end use application desired. The SBT waste processing area is thus developed into a green belt or garden, which easily integrates into any existing landscape.*

### **Input parameter**

*SBT is used to remove SS, Organic and inorganic contents of the wastewater. Mostly used for sewage treatment and it is designed for disposal of domestic waste water and treats them for reuse. SBT can be*

used for arsenic/iron removal, hospital waste processing, and industrial waste water processing and industrial air pollution.

### Major Elements of SBT

1. Media which supports the micro & macro organisms of soil ecology for aerobic respiration which includes nitrogen fixation and active oxygen production.
2. Culture which includes geophagus worms serves as the top carnivore to regulate soil population.
3. Additives: a natural mineral mixture which regulates pH.
4. Green plants to serve as bio indicator of the health of process. In view of the ecology of soil & engineered natural oxygen supply highly aerobic environment exists in the bioreactor.

### Chemistry of Soil Biotechnology

#### Respiration



#### Photosynthesis



#### Nitrogen Fixation



#### Acidogenesis



#### Methanogenesis





(Adding 5 and 6 give overall biomethanation chemistry)



*Mineral weathering*



*Nitrification*



*Denitrification*



### ***Water Reuse Possibilities after Treated Wastewater from Soil Biotechnology***

- Gardening
- Toilet Flushing
- In Construction activities and Industrial floor washing
- Car Washing

- *For HVAC (Heating, ventilation and air conditioning ) Cooling Tower*
- *Ground Water Recharge after getting desired norms of SPCB*
- *Release to Water Bodies*

*SBT systems are typically housed in RCC, stone-masonry or soil bunds and consists of an impervious contaminants. It starts with a under drain layer, above which lies a layer of media housing culture and bio indicator plants. Water initially passes through the additive layer and subsequently passes through the media. It can be run as single stage or multistage, depending on desired water quality. The recirculation is provided for further polishing if required.*

### ***Industrial Application of SBT***

- *Effective COD handling*
- *Polishing unit for existing CETPs*
- *MEE condensate treatment for Pharma and Chemical Industries.*
- *Pharmaceutical Effluent (Formulation & API) Chemical Research Organizations (CRO's), Biotech companies*
- *Ammonia rich wastewater: Fertilizer Industries*
- *Petrochemicals, Pesticides, Sugar Effluents, Distillery Condensate recycling*
- *Arsenic removal upto extent of 98.6 %*
- *Fe removal upto 97.5 %*
- *Phosphorous removal upto 93 %*

### ***In Industry, technology is being extended for zero liquid discharge for following applications***

- *Pharma (API & Formulations)*
- *Petrochemicals*
- *Pesticides*
- *Textile*
- *Dye Intermediates*
- *Wineries, Sugar Industries & Distilleries*
- *Pulp & Paper Mills*

### *Salient features*

- *The process can be run on batch or continuous mode.*
- *No sludge production*
- *Mechanical aeration is not required.*
- *The overall time of operation is 6-7 hours per day.*

### *Advantages*

- *The process can be run on batch or continuous mode.*
- *No sludge production & Mechanical aeration is not required.*
- *The overall time of operation is 6-7 hours per day. The soil biotechnology system bed is dried prior to next cycle of use.*
- *Life of the specially constituted filtering media bed of SBT is long (tens of years) since with time the natural living agents multiply or shrink to optimal levels based on the actual chemical and biological load in the system.*
- *Low on energy consumption, Low on mechanization, hence zero down time.*
- *No disposables or process residues. Potential for Zero Discharge, No air or sound pollution. Free from foul odor using natural ingredients against synthetic chemical.*
- *Scalable to any size of operation, Best option for decentralized wastewater treatment. Ideal for getting high Green Rating, Carbon Credits. Ideal option for implementation.*
- *Colorful green landscape as a by-product. Water recovery - 90% (Minimum) 100 % of treated water is being reused in horticulture.*
- *The revenue from horticulture(gardening) comes to Rs. 1.5 Lakh p.a. The by-products from waste water treatment system based on SBT are Biomass and Bio-fertilizer.*
- *Biomass in the form of flower, fodder, fruit and fibre which is utilized. The bio fertilizer rich in organic and slow release minerals are also utilized in horticulture. Max 2 Metric Tons /yr. of bio-fertilizer can be generated from the system as by-product.*
- *Any form of unsafe sewage disposal is completely avoided; it prevents a form of damage to the local ecology.*



- Being a relatively low energy consuming operation, the carbon foot print of the entire treatment plant is much lower than the modern sewage systems. No toxic waste and foul smell is produced.<sup>8</sup>

### ***SBT at Govardhan Eco village (GEV), Maharastra (CASE STUDY)***

*SBT of Govardhan Eco village consists of an impervious containment and incorporates soil, formulated granular filter media, select culture of macro organisms such as earthworms and plants.*



***Figure: Step 1 – Collection Tank***



***Figure: Step 2 – Side view of the plant bed***



***Figure: Step 3 – Water being sprayed on the plant bed***



***Figure: Step 4 – Collection of the treated water***

*It involves a combination of physical and biological process for processing of wastewater. The combined grey and black water from all the residential facilities are collected and transported via water based underground sewerage network to a central collection point. In the first stage the physical separation of waste is accomplished in a primary treatment unit consisting of a perforated screen and gravity-settling tank and an equalization tank. The perforated screen helps in separating the undissolved solid wastes from the waste water and allows it to pass through a settling chamber that has a sloped bottom opposite to the direction of the water flow, thus facilitating the settling of solid particulates with higher specific gravity than the waste stream. Then the water enters the open top equalization tank that allows the dissolved pollutants to be exposed to natural sterilization by sunlight and ambient air.*

*In this second stage the wastewater is sprayed, by means of a pump, onto a plant bed which is part of an engineered ecosystem that constitutes two bio-reactors, one for a coarse purification and the other for further refining through recycling. **This ecosystem consisting of soil, bacterial culture and earthworms, mineral additives and select plants,** treats the water is a combination of physiochemical and biological processes. Purification takes place by adsorption, filtration and biological reaction. The entire waste is processed and converted into bio-fertilizer which is rich in organic content, and is being used in the plant nursery at GEV. The other useful by-product is the Biomass in the form of flower, fodder, fruit and fiber which are also completely utilized in house. Since the entire waste is converted, there are no issues like handling the wastes after treating the water, as is common in conventional chemical based sewage treatment plants. The entire process operates in aerobic mode thus eliminating the possibility of foul odor near the plant, creating a safe and serene ambiance for the people dwelling near the plant. The processed water can be reused in gardening, agriculture and also support marine life.*

*The SBT plant at GEV can handle up to 30,000 litres of sewage per day and operates in an 8 hour cycle daily. It can potentially produce up to 20,00,000 Tons of bio-fertilizer per year and most importantly offers an eco-friendly option to the growing menace of waste handling.<sup>9</sup>*

**Table 2.1 Impact and Sustainability**

Parameter	Conventional	Soil Biotechnology
<b>Benefits of Separation of streams output</b>		Synthesis of resource (waste) molecules into usable output products

<b>Odor</b>	<i>Pungent Smell due to ammonia and aerosols generated from aqueous phase aeration device</i>	<i>No possibility of aerosol generation. Smell control is achieved via natural additive addition and high rate ammonia oxidation</i>
<b>Sludge Generation</b>	<i>Chemical and biological sludge is produced as waste by product which needs further handling like dewatering and dry for disposal</i>	<i>No sludge is produced. Bio-mineral fertilizer is produced as useful by-product</i>
<b>Energy</b>	<i>All conventional aerobic treatment processes are based on aqueous phase reaction and therefore mechanical aeration is energy intensive</i>	<i>Process driven by Natural Aeration in engineered soil ecosystem it is also energy conservative</i>

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### SBT Field Reports

#### SCL – Chandigarh

Type	API Unit
Capacity	10 KLD
Type of Effluent	MEE Condensate + Effluent
Inlet COD	6000-10000 mg/L
Outlet COD	120-150 mg/L
Commissioned	Feb. 2013

#### Zydus Cadila - Ahmedabad

Type	Formulation Unit
Capacity	200 KLD
Type of Effluent	Process Effluent
Inlet COD	1500-2500 mg/L
Outlet COD	60-80 mg/L
Commissioned	March 2013



*Anupam Rasayan – Surat*

Type	Pharma API & Intermediate
Capacity	75KLD
Type of Effluent	MEE Condensate
Inlet COD	Less than 5000mg/L
Outlet COD	Less than 200mg/L
Commissioned	October 2014

*SBT – Few Installations*

*HEROHGALLI Bangalore, Karnataka*



*AIPORT AUTHORITY OF INDIA Udaipur, Rajasthan*

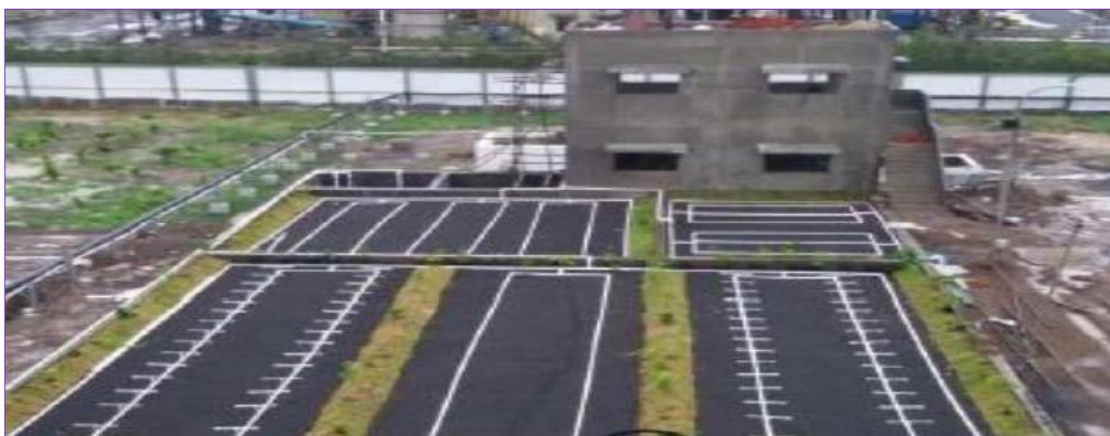




*NAVAL HOUSING COLONY Kanjurmarg, Mumbai*



*NOCIL DAHEJ, Gujarat*



*ZYDUS CADILLA Ahmedabad, Gujarat*





*ADROIT PHARMA Vadodara, Gujarat<sup>11</sup>*



### (3) Reed Bed Technology (RBT)

#### Description

Reed beds use common reed plants (*Phragmites communis*, a second cousin of the common marsh plant) to dewater solids in a confined area. The beds can be any shape to accommodate existing land conditions and areas. Specially designed ponds with underdrains covered by a sand and gravel mixture are constructed and filled with reed plants. Modified sludge drying beds also work well and are an ideal retrofit. They already have side walls, layers of sand and gravel, an underdrain system which collects and carries away filtrate, and an impervious membrane liner. Solids are pumped into the reed beds. Dewatering occurs through evaporation, plant transpiration, and decantation. Decanted water seeps through the bottom of the bed and through the layers of sand and gravel into the underdrains, traveling back to the wastewater treatment plant for secondary treatment. During dewatering the solids change from liquid to "cake." Six inches of solids and water will compress to a half inch of solid cake. The cake is left in the bed and the process is repeated.



#### Working of Reed Bed Technology

The reeds are planted one foot on center throughout the bed. Aerobically stabilized sludge or effluent is typically applied uniformly through a grid-perforated tile. Sludges or effluent must be well stabilized, 60% volatilized or less to be used successfully with reed beds. Optimum application rates range between

*two and four percent solids. While plants are young they should be watered with plant effluent. After they are established, they can be fed heavier sludge mixtures. Loading rates in Maine are typically about 45 gallons per square foot per year for well-established beds.*



*The Phragmites is one of the most widespread flowering plants in the world. It is a tough adaptable plant, which can grow in polluted waters and find sustenance in sludge. This reed has a voracious appetite for water. The plant is tolerant to low oxygen levels and to waterlogged conditions. The reeds hold themselves in the soil through roots and rhizomes, an intricate network of underground stems. New plants in turn will sprout from these stems. These rapidly growing roots provide air passages through the sludge which in turn provide a host area for many biological communities to develop and continue to mineralize the sludge.*

*Reed beds perform three basic functions: (1) dewater the sludge, (2) transform it into mineral and humus like components, and (3) store sludge for a number of years. Dewatering is accomplished through evaporation (as in a normal sludge drying bed operation); transpiration through the plants root stem, and leaf structure; and filtration through the bed's sand and gravel layers and the plant's root system. Leachate is channeled back to the treatment plant through the underdrain. The plants should be harvested annually to prevent drainage backup. The vegetation can be composted or burned.<sup>12</sup>*

### ***Microbial Activity***

*Micro-organisms attach themselves to the outside of the gravel or soil particles and to the plants and plant roots. These organisms metabolise polluting chemicals, degrading and mineralising them. Commonly reed beds are used to degrade sewage, but with higher retention times even intractable compounds such as PAH, PCB, dyestuffs, amines and glycols can be treated.*

### ***The Role of Plant***

***The specially selected plant species (Phragmites species e.g. Phragmiteskarka and Typhaangustus) within the Reed bed have the following three main functions:***

*They provide the means for secondary restructuring of the soil system. The very extensive root and rhizome system creates channels for the water to pass through and also keeps the soil open through the constant growth. The roots of the aquatic plant introduce atmospheric oxygen down into the body of soil, facilitating the diversity of microorganisms to flourish around the plant roots. It is essential for the effective breakdown of various organic and inorganic compounds. The plants are capable of taking up a certain amount of nutrients from the wastewater itself.<sup>13</sup>*

### ***Choosing Media***

*The choice of bed media, gravel, soil or sand, is dependent upon the particular application requirements. Gravel is less active microbiologically, but allows a faster throughput of water. For this reason, gravel has commonly been used in secondary and tertiary sewage treatment applications and in mine waste water treatment where the plants help to keep the water oxygenated thus encouraging the deposition of insoluble metal ions precipitates. Soil has commonly been used for primary and secondary treatment of industrial effluents. Certain soil minerals actually encourage the deposition of metal ions, phosphate and sulphate. Soils can therefore be custom-engineered to treat particular effluent streams. In addition, the ability of clay particles and humic materials to entrap polluting chemicals means that the soil system can cope with shock loads.<sup>14</sup>*

### ***Features of Reed Bed Technology***

- ***Operation and maintenance free:*** The reed bed system has no mechanical/moving parts. There is no wastage of energy as mechanical aeration is not needed.
- ***Clean and efficient:*** Since all chemical, physical and biological changes occur underground, there are no strong odors or sludge formation.
- ***Self-sustaining and long lasting:*** Once installed and become operational, the reed bed system can sustain itself for more than 40 years.

- **Adaptability:** The reed bed systems are suitable for concentrations from a few mg/l to 20,000 mg/l of COD and 400 mg/l of nitrogen. Their capacity varies from about 1m<sup>3</sup>/day to more than 10,000 m<sup>3</sup>/day.
- **Can handle difficult effluents:** As the reed bed system has diversity of microbes and the wetland and the plants, it can adapt itself to diverse types and varying shock loads of effluents, including difficult waste waters containing:
  - ✓ Organic compounds like Chlorinated hydrocarbons, dyes and sulphur containing aromatics.
  - ✓ Nitrogen compounds such as ammonia and nitrates.
  - ✓ Sulphur compounds like sulphides and sulphates.
  - ✓ Heavy metals and pathogens.

### **Design Consideration**

**Reed beds should have the following:**

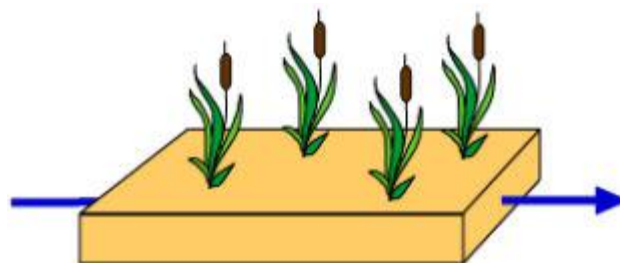
- Impermeable liner or base to protect groundwater.
- Outer walls 6 to 8 feet high made of concrete with footers.
- Loading of liquid biosolids from manifold and risers along the long sides, typically three per side.
- Beds of up to 100 feet long and up to 50 feet wide.
- Adequate access for bed clean-out.
- The beds should be sized based on allowable loading rate and biosolids production during the winter and early spring dormant phase.
- Design the beds with enough redundancy so that, after six years, one bed at a time can be removed from service to dry out, remove solids and re-establish the plants.



## ***Reed Bed based on type of Construction***

### ***1. Surface Horizontal Flow (SHF)***

*This design allows water to flow over the surface of the bed between the stems of the reed plants which are planted in earth. The water is visible, usually to a depth of around 150mm. The design is effective for settling out solids prior to further treatment, or to balance flows into further reed bed stages.*



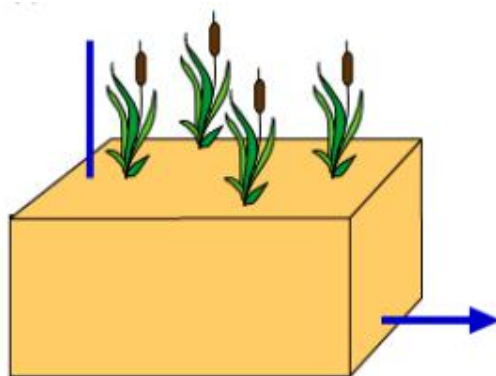
***Figure 3.1 HORIZONTAL FLOW WETLAND***

### ***2. Subsurface Horizontal Flow (SSHF)***

*This design allows water to flow below the surface of the reed bed through gravel media. The reed plants are planted in the gravel. There is no visible water in the bed and as such presents no public safety or odor problems. The reed plants are allowed to dieback in winter and form a warm composted layer which protects the biofilm below. This design is effective in reducing SS, BOD, COD and partial ammonia removal. It is also effective in removal of hydrocarbons, some heavy metals and nitrates.*

### ***3. Down Flow or Vertical Flow (VF)***

*This design requires dosing of the bed's surface using a network of pipes using either a pumping or a siphon system. The idea is to flood the surface of the reed bed a number of times per day. As the water flows down through the bed, it draws air in, creating the right bacterial environment. VF reed beds are very effective in removal of BOD, ammonia and some heavy metals and take up less area for similar treatment compared to SSHF. The efficiency of SSHF and VF reed beds may be improved by adding certain chemicals to the water during the treatment. This dosing technique can be used for COD or phosphorous removal in industrial process water, for example. Water can be treated progressively through multiple reed bed stages and some or all of the above systems can be incorporated into a complete treatment system.<sup>15</sup>*



**Figure 3.2 VERTICAL FLOW WETLAND**

### **Advantages**

- *Reed beds have relatively low operational costs compared to conventional biological treatment systems. As flow through the system is governed by gravity, there are no requirements for pumping once the effluent is in the reed bed. Similarly, as aeration is facilitated by the reeds, there is no requirement for blowers to aerate the system. As such, there are no mechanical or electrical requirements.*
- *They do not produce sludges, a significant problem in the operation of conventional biological systems.*
- *Due to the low tech nature of reed beds, there is no requirement for highly trained operators.*
- *As the degradation of the organic content of the effluent occurs within a solid matrix, it should be free from odor.*
- *High adaptability to both concentration and content of effluents. As reed bed systems have a high diversity of microorganisms, they may adapt to diverse types and varying shock loads of effluents, including difficult waste waters containing organic compounds, such as chlorinated hydrocarbons, dyes and sulphur containing aromatics and heavy metals and pathogens.<sup>16</sup>*



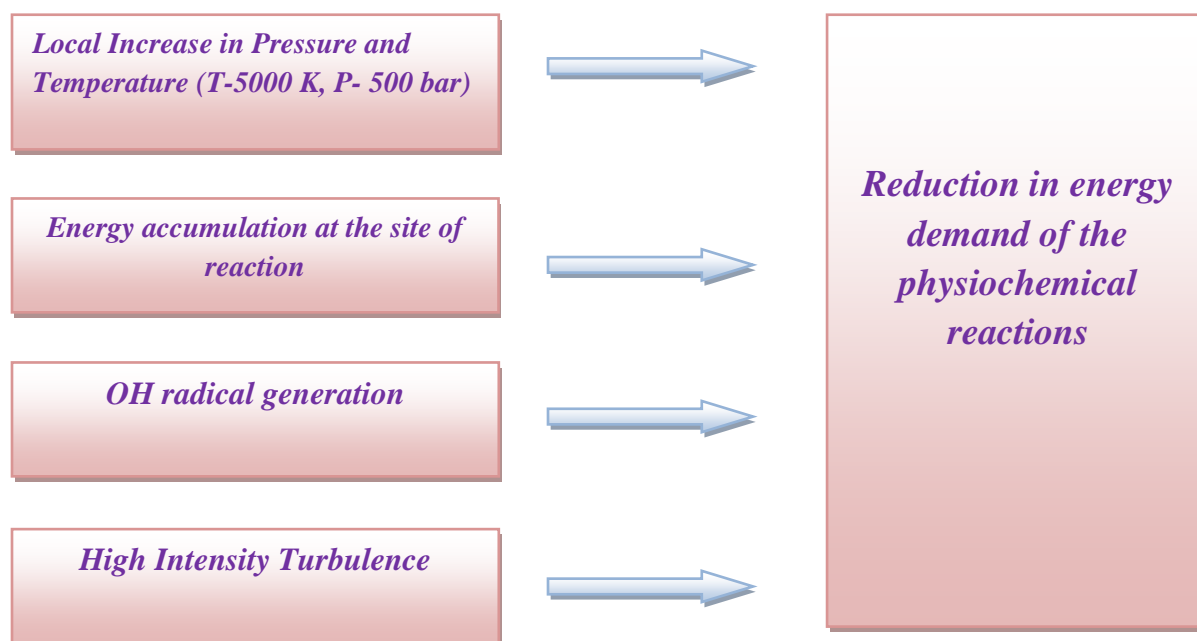
### *Disadvantages*

- *While capital costs of reed beds vary, the beds can significantly reduce staff hours and costs required to dewater with conventional sand drying beds or with mechanical systems such as a belt press or centrifuge.*
- *For dewatering equipment, you need a separate building and you also have to pay people to haul the sludge away and landfill.*
- *It costs a lot to run even a small belt press, so if you have the land available, reed beds may make sense.*
- *About the only disadvantage is there can be some odor in the spring when the ice melts, but that usually only lasts a couple of weeks. So, use a concrete bottom instead of a PVC liner. Operators have to be careful that they don't go through the liner when they clean out the beds.*
- *The importance of protecting the perforated pipes and the drains from damage. During clean-out or maintenance, the weight of even a small front-end loader can crush the underdrains.*
- *One misconception is that the reeds can spread and become invasive. "It was thought that the roots would start to re-grow in the fields, but that's not a problem if the soils are well drained,"<sup>17</sup>*

#### ***(4) Hydrodynamic cavitation (HDC)***

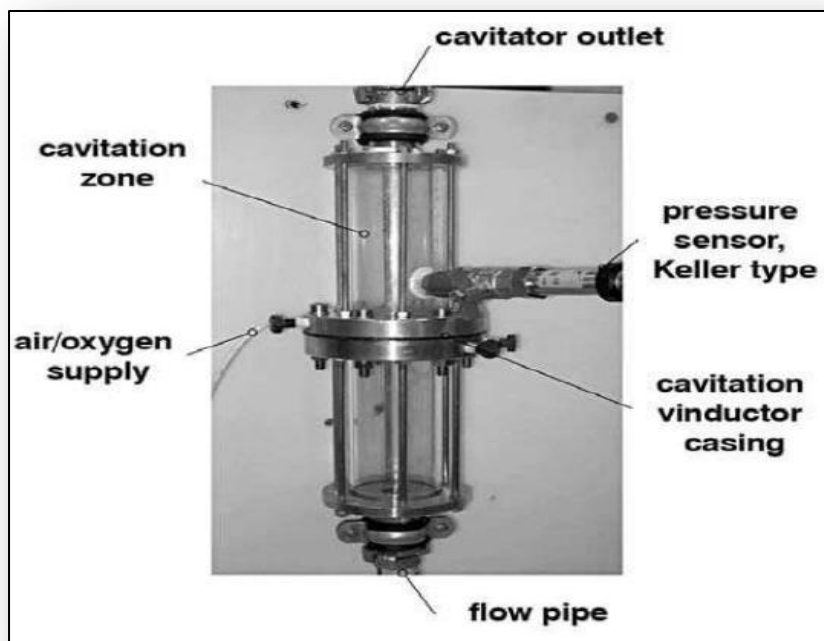
##### ***Description***

*Cavitation phenomena are associated with the formation, growth and the collapse of micro bubbles and consequently, to the generation of very high pressures, shear stresses and temperatures, locally. By virtue of lower process costs and a less complex structure of reactors, hydrodynamic cavitation comes to the fore as the prospective method for the degradation of organic contaminants found in wastewater. The mechanism behind the phenomenon of hydrodynamic cavitation is the formation, growth and subsequent collapse of cavitation bubbles in the flowing liquid. Cavitation bubble implosion is accompanied by a host of physicochemical phenomena.*



**Figure 4.1 Physiochemical Phenomenon inside the Hydrodynamic Cavitation Reactor**

Source: (Szulzyk-cieplak, J et al)

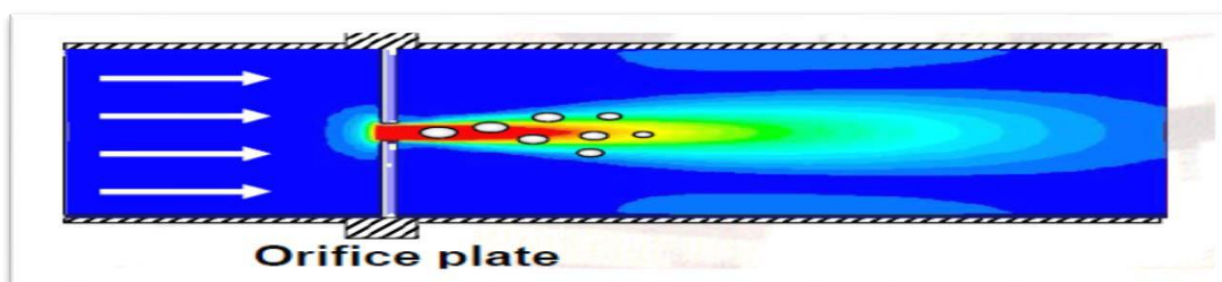


*Figure 4.2 Hydrodynamic cavitation Reactor*

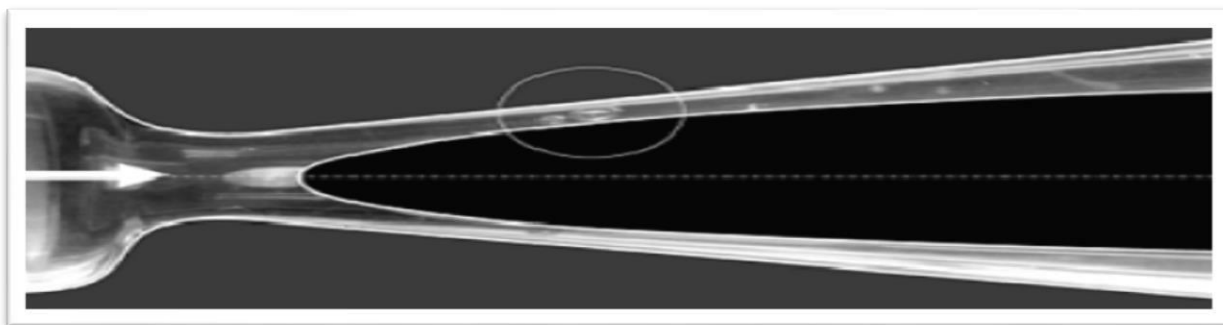
Source: (Szulzyk-cieplak, J et al)

The pH of the waste water is raised to 10.5 by **hydrated lime** and filtered. The waste water is then pumped through a hydrodynamic cavitator. This is a batch process and the system is kept under recirculation till the COD is reached to desired limit. This is again filtered in the filter press and the filtered waste water is sent for further treatment or disposal or to water recycling unit.

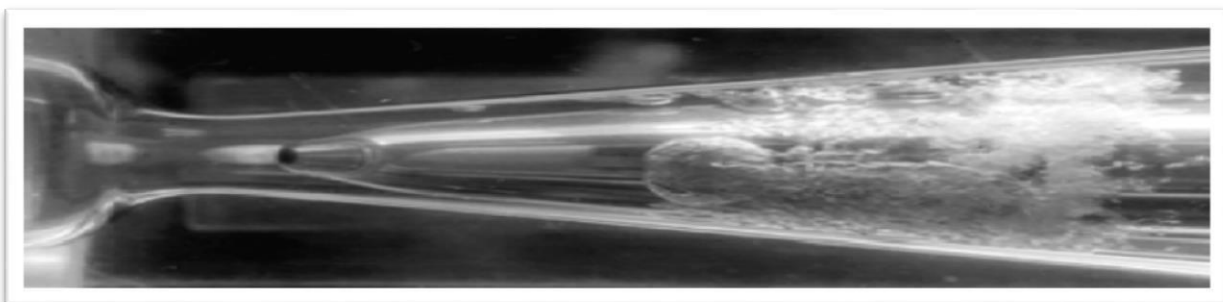
#### *Mechanism of Hydrodynamic Cavitation Technology*



*Figure 4.3 Turbulent fluctuating pressure field Hydrodynamic Cavitation)*



*At low flow rate, water is everywhere free of cavitation. Velocity is maximum in the section of minimum area and pressure is then minimum. When the flow rate is progressively increased, the minimum pressure decreases and there will be a critical flow rate for which the vapor pressure is obtained at the throat. At this operating point, cavitation appears in the section of minimum area. In Figure, two bubbles are clearly visible in the upper part of the Venturi. This is the start of the cavitation state.*



*If the flow rate through the venturi is further increased, the extent of cavitation increases. At this point the **chlorine** when injected will oxidize the organic matter in exploded bubble and due to the large surface area available, the oxidation by chlorine molecule is almost instantaneous.*

### Key Effects in the Cavitating zone

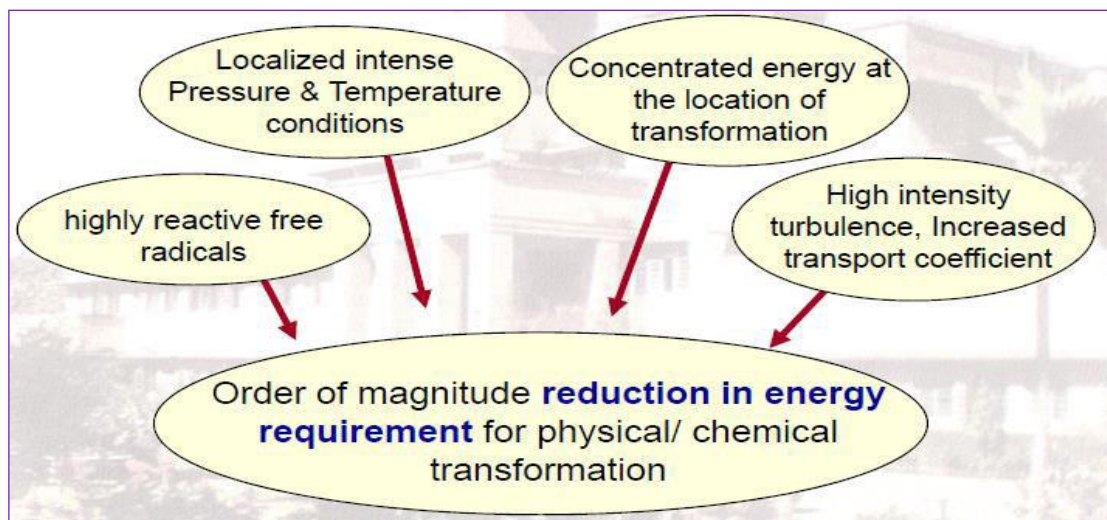


Figure 4.5 Key Effects in the Cavitating zone

### Input Parameter

The organic wastewater discharged from industries consists of large amounts of **dyes and other toxic pollutants** which can be harmful to human health and ecosystem causing environmental pollution. The presence of cyanides and organic wastes in water is a concern since industrial effluents generated from metallic industries, electroplating, steel hardening, synthetic rubber production, and organic synthesis usually contain free and metal or cyanide complexes. They are highly toxic and cause a series of diverse and irreversible damages to the environment and health of the public. Hence, there is a need for treating the wastewater by developing additional methods like Hydrodynamic cavitation so that it can be reused for various purposes in industries and localities.

### Advantages

Hydrodynamic cavitation is used as a pre-treatment with an aim of reducing the overall cost of pollutant degradation. It has been observed that approach of latent remediation works quite well with about 50–60% removal of TOC using only minimal initial treatment by hydrodynamic cavitation. The reactor equipped with number of venturies which is easy to install & operate. Existing Conventional treatment unit can be converted into Hydrodynamic Cavitation reactor. The cost of venturies is quite less.

Removal of COD is 60- 90 %, based on different type of wastewater and also retention time for specific type of wastewater. Colorless wastewater obtained from Hydrodynamic cavitation technology. Odor is not a major problem from the wastewater which is treated by hydrodynamic cavitation technology. Large-scale operation coupled with better energy efficiency makes this technique a viable alternative for conventional cavitational reactors. It is one of the cheapest and most energy efficient method of generating cavitation and capable of generating highly reactive hydroxyl radicals. Independent of the wastewater composition, wastewater having high COD can be treated more effectively. The equipment used for generating Cavitation is simple. Maintenance of such reactors is very low. The scale-up of the process is relatively easy. Reactions that require moderately rigorous conditions can be carried out at ambient conditions. The cavitational yield is defined as the ratio of the cavitational effect (moles of dye degraded) to the total energy input to the system. Cavitational yield for the hydrodynamic cavitation is higher as compared to any of the ultrasonic equipment studied for the degradation. The hydrodynamic cavitation is more energy efficient as compared to acoustic cavitation and almost 13 times higher cavitational yield was obtained in case of hydrodynamic cavitation as compared to acoustic cavitation. It is a greener technology that does not necessarily need additional chemicals. It can be coupled with other AOPs, if required. Bulk temperature is ambient; bulk pressure is in range of 3-atmosphere and enhances performance of existing effluent treatment facility (improves efficiency of aerobic reactor, increases biodegradability of effluent (BOD: COD ratio), reduces COD of effluent etc.). It can operate with lower overall pressure drops and hence lower net energy consumption. It can be designed and operated practically for any pressure and flow rate. It can be fabricated in any material of construction for high wear and tear, corrosive resistance and high pressure & temperature application.

### ***Pesticide Wastewater Treatment by Hydrodynamic Cavitation Process at Vadodara, Gujarat (CASE STUDY)***

The untreated waste water sample of pesticide industry was collected from the inlet of the effluent treatment plant of the industry located near Vadodara, Gujarat. Sample was stored at 4 °C immediately after collection of the waste water.

For hydrodynamic Cavitation, experiments were performed in reactor of capacity 50 liters in which effluent was lifted and circulated by the pump of capacity 1 H.P. for different intervals of time and chlorine was used as an oxidizing agent. Sample was kept for quiescent condition for 2 hours for the settlement of the precipitates. All experiments were carried out in batch mode. Several set of



experiments were carried out to check the optimum range of time. All the Experiments were carried out in normal atmospheric temperature at 28°C. The Cavitation reactor was fabricated at perfect engineering services, Vadodara. All the chemicals used for the measurement of parameters were obtained from MERCK.



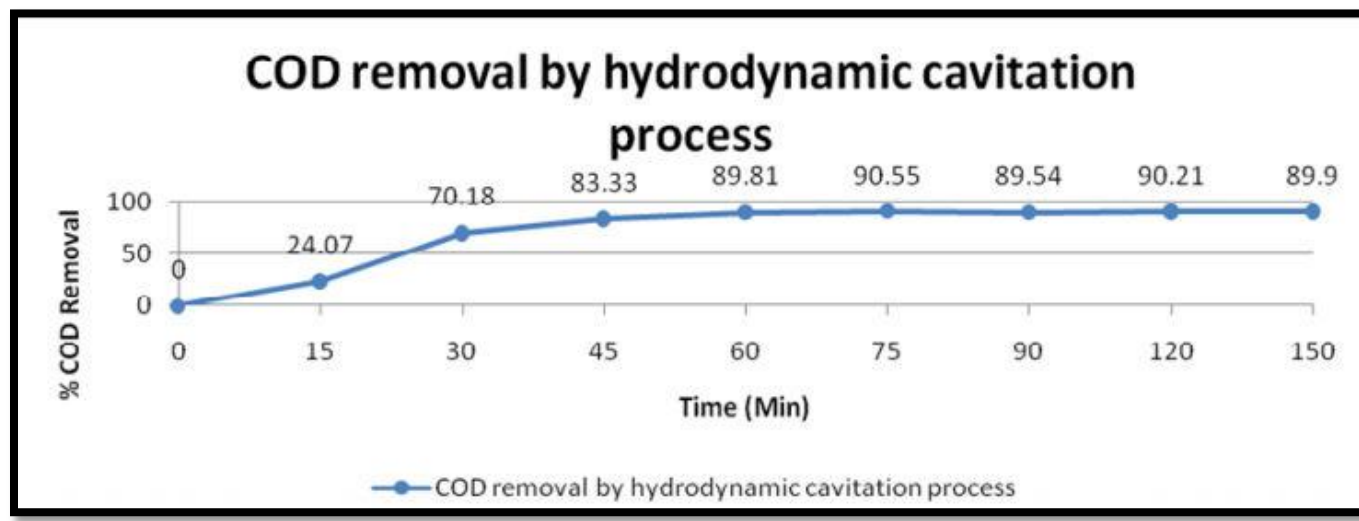
*Figure 4.6 Hydrodynamic Cavitation Reactor*

*Table 4.1 Raw Effluent Characteristics*

<i>SR. NO</i>	<i>CHARACTERISTICS</i>	<i>RAW EFFLUENT</i>	<i>AFTER TREATMENT (75 min)</i>
<i>1</i>	<i>Ph</i>	<i>8.1-8.5</i>	<i>6.6-6.8</i>
<i>2</i>	<i>COD</i>	<i>10200-10800 mg/L</i>	<i>1020 mg/L</i>
<i>3</i>	<i>TDS</i>	<i>90000 mg/L</i>	<i>18200 mg/L</i>
<i>4</i>	<i>TSS</i>	<i>13500 mg/L</i>	<i>2160 mg/L</i>
<i>5</i>	<i>Colour</i>	<i>7970 (Pt-Co Scale)</i>	<i>1338(Pt-Co Scale)</i>



The wastewater characteristics play a significant role on its treatment. Raw wastewater characteristics were measured and listed in Table 4.1. These results indicate that this wastewater contains high load of organic and inorganic matter. Therefore, this wastewater can cause damage to the environment when discharged directly without proper treatment.



**Figure 4.7: 2 % COD removal by hydrodynamic cavitation process**

In this study, the effect of Cavitation was examined for the different time intervals from 0 to 150mins. In hydrodynamic cavitation pump was used of 1 H.P capacity and reactor was 50 liters. With hydrodynamic Cavitation, maximum COD removal achieved was 90.55% in 75 mins as shown in the graph. Also it is observed that between 60- 150mins the removal efficiency is almost same. Also the Reduction of TDS was observed by 79.77% and TSS reduction by 84.00% in 75 mins. There was also significant reduction in colour. The colour removal on Pt-Co Scale was observed as 83.21%. All the experiments were carried out according to APHA, Standard methods for the examination of water and wastewater, 21st edition, American Public health association, Washington D.C, USA, 2005.<sup>18</sup>

## **(5) Membrane Bio reactor (MBR)**

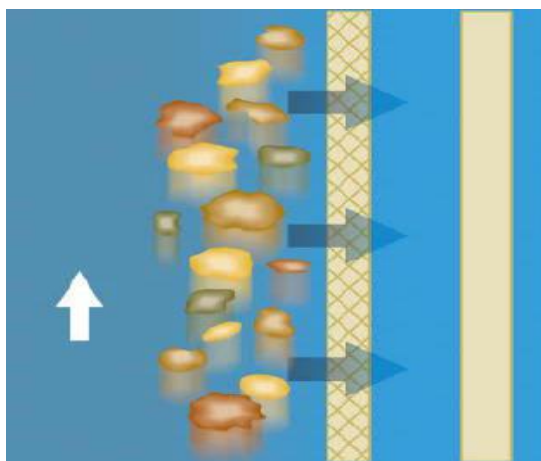
### **Description**

*MBR technology is based on the combination of conventional activated sludge treatment together with a process filtration through a membrane with a pore size between 10 nm and 0.4 microns (micro/ultra filtration), which allows sludge separation. The membrane is a barrier that retains all particles, colloids, bacteria and viruses, providing a complete disinfection of treated water. Furthermore, it can operate at higher concentrations of sludge (up to 12 g/l instead of the usual 4 g/l in conventional systems), which significantly reduces the volume of the reactors and sludge production. Although there are two main process configurations of biomass rejection MBRs, submerged or immersed (IMBR) and sidestream (SMBR), the immersed configuration is the most widely used in municipal wastewater treatment due to lower associated costs of operation. In this configuration, the module is placed directly into the process tank and is thus less energy-intensive. As a result, it is only necessary to create a slight vacuum inside the membrane module, measured as Transmembrane pressure (TMP) for filtration.*

*For the immersed configuration, there are basically two types of commercial membrane modules available: flat sheet (FS), and hollow fiber (HF). HF allows a higher packing density since it has a thinner space between membranes compared to FS. However, this makes it more susceptible to membrane clogging and/or sludging and it can also make cleaning more difficult. Regarding the membrane material used for an IMBR, fluorinated and sulphonated polymers (polyvinylidene, difluoride, polyethersulfone, inparticular) dominate in commercial membrane MBR products. It is necessary to study the mechanisms and factors that contribute to membrane fouling in MBR. Generally, these factors have been classified in four distinct groups: nature of the sludge, operating parameters, membrane/module characteristics and feed wastewater composition.*

## Membrane filtration

Membrane filtration involves the flow of water-containing pollutants across a membrane. Water permeates through the membrane into a separate channel for recovery. Because of the cross-flow movement of water and the waste constituents, materials left behind do not accumulate at the membrane surface but are carried out of the system for later recovery or disposal. The water passing through the membrane is called the permeate, while the water with the more-concentrated materials is called the concentrate or retentate.



**Figure 5.1 Membrane filtration process**

Membranes are constructed of cellulose or other polymer material, with a maximum pore size set during the manufacturing process. The requirement is that the membranes prevent passage of particles the size of microorganisms, or about 1 micron (0.001 millimeters), so that they remain in the system. This means that MBR systems are good for removing solid material, but the removal of dissolved wastewater components must be facilitated by using additional treatment steps.



**Figure 5.2 Hollow-fiber membranes**

*Membranes can be configured in a number of ways. For MBR applications, the two configurations most often used are hollow fibers grouped in bundles, as shown in Figure 5.2, or as flat plates. The hollow fiber bundles are connected by manifolds in units that are designed for easy changing and servicing.*

### ***Design and operation considerations***

*As was previously mentioned, the IMBR represents the most widely used configuration in large scale applications. This section gives some design and operation considerations including:*

- (1). Pre-treatment,*
- (2). Design flux, hybrid systems and equalization tanks,*
- (3). Membrane fouling control and cleaning,*
- (4). Sludge retention time and biomass concentration, and*
- (5). Membrane life*

#### ***(1). Pre-treatment***

*Membranes are very sensitive to damage with coarse solids such as plastics, leaves, rags and fine particles like hair from wastewater. In fact, a lack of good pre-treatment/screening has been recognized as a key technical problem of MBR operation. For this reason fine screening is always required for protecting the membranes. Typically, screens with openings range between 1 mm (HF modules) to 3 mm (FS modules) are common in most facilities. Regarding primary sedimentation, it was not economically viable for small-medium sized MBR plants (< 50.000 m<sup>3</sup>/d), except for cases of retrofitting or upgrading of an existing CAS. However, for larger plants, given its advantages (smaller bioreactor volumes, reduced inert solids in the bioreactor, increased energy recovery, etc.), primary clarification can be considered. Its selection should be a compromise between energy and land cost.*

#### ***(2). Design flux, hybrid systems and equalization tanks***

*Membrane permeate flux is an important design and operational parameter that impacts significantly in CAPEX and OPEX. Typical operation flux rates for various full-scale IMBRS applied to treat municipal wastewater treatment are over 19-20 l/h m<sup>2</sup>. It is interesting to note that for both systems the operation net flux is over 18 l/h m<sup>2</sup>.*

### **(3). Membrane fouling control and cleaning**

*It is generally accepted that the optimal operation of an MBR depends on understanding membrane fouling. Abatement of fouling leads to elevated energy demand and sand has become the main contribute on to OPEX.*

*Membrane fouling can be controlled by:*

*(1) Air sparging, expressed as specific aeration demand SADm, takes a typical value for full-scale facilities between 0.30 Nm<sup>3</sup>/h m<sup>2</sup> (FS configuration) to 0.57 Nm<sup>3</sup>/h m<sup>2</sup> (HF configuration).*

*(2) Relaxation and back flushing (only for HF), which are commonly applied for 30–130 seconds every 10–25 min of filtration (Judd, 2010).*

*(3) Frequent maintenance cleanings (every 2–7 d) are also applied to maintain membrane permeability.*

### **(4). Sludge retention time (SRT) and biomass concentration**

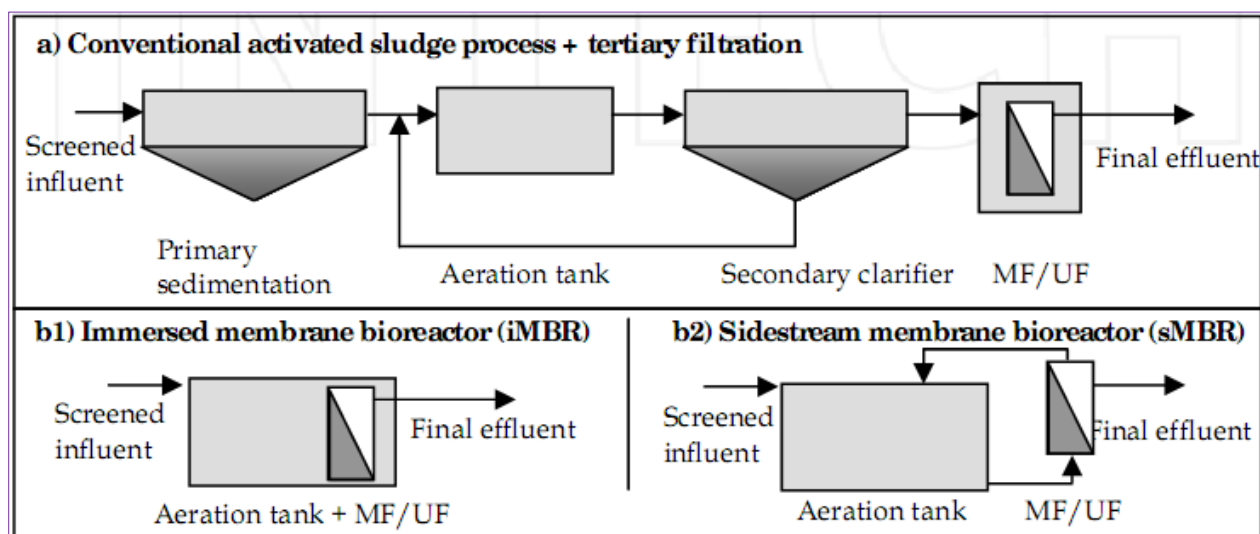
*SRT contributes to a treatment performance and membrane filtration, and therefore, to system economics. Specifically, these parameters act on biomass concentration (MLSS), generation of soluble microbial products (SMP) and oxygen transfer efficiency. Increasing the SRT increases the sludge solids concentration and therefore, reduces bioreactor volume required. Furthermore, because of the low growth rates of some microorganisms (specifically nitrifying bacteria), a longer SRT will achieve a better treatment performance, as well as generating less sludge. In addition, it has been reported that high values of SRT can increase membrane permeability. Conversely, high solids concentration results in a higher viscosity of the microbial suspension, as a consequence, higher concentrations decrease air sparging efficiency and oxygen transfer rate to the microorganisms, resulting in a higher energy demand as well as increasing membrane fouling and the risk of membrane clogging. MBRs are mostly designed for MLSS range of 8-12 g/l and SRT range of 10-20 d.*

### **(5). Membrane life**

*Membrane life can reach, or even exceed, 10 years. Regarding permeability, a correlation of permeability loss and operation time was found as per many researches, indicating that the membrane permeability reaches non-operative value after seven years of operation.<sup>19</sup>*

## Advantages and challenges

MBRs represent an important technical option for wastewater treatment and reuse, being very compact and efficient systems for separation of suspended and colloidal matter and enabling high quality, disinfected effluents to be achieved. A key advantage of these MBR systems is complete biomass retention in the aerobic reactor, which decouples the sludge retention time (SRT) from the hydraulic retention time (HRT), allowing biomass concentrations to increase in the reaction basin, thus facilitating relatively smaller reactors or/and higher organic loading rates (ORL). In addition, the process is more compact than a conventional activated sludge process (CAS), removing 3 individual processes of the conventional scheme and the feed wastewater only needs to be screened (1-3 mm) just prior to removal of larger solids that can damage the membranes.



**Figure 5.11** Conventional activated sludge process (a) and MBR in both configurations: immersed (b1) and sidestream (b2)

Notwithstanding the advantages of MBRs, the widespread implantation is limited by its high costs, both capital and operating expenditure (CAPEX and OPEX), mainly due to membrane installation and replacement and high energy demand. This high energy demand in comparison with a CAS, is closely associated with strategies for avoiding/mitigating membrane fouling). Fouling is the restriction, occlusion or blocking of membrane pores or cake building by solids accumulation on the membrane surface during operation which leads to membrane permeability loss. The complexity of this phenomenon is linked to the presence of particles and macromolecules with very different sizes and the



biological nature of the microbial suspensions, which results in a very heterogenic system. Meanwhile, the dynamic behavior of the filtration process adds a particular complication to the fouling mechanisms. Permeability loss can also be caused by channel clogging, which is the formation of solid deposit in the voids of the membrane modules due to local breakdown of cross flow conditions. In addition, there are other operational problems, such as the complexity of the membrane processes (including specific procedures for cleaning), the tendency to form foam (partly due to excessive aeration), the smaller sludge dewatering capacity and the high sensitivity shock loads.

### Disadvantages

Uses more electricity; high pressure system can be energy-intensive. May need pretreatment to prevent fouling; pretreatment facilities increase space needs and overall costs. It may require residuals handling and disposal of concentrate. Require replacement of membranes about every 3 to 5 years. Scale formation can be a serious problem. Flux rate gradually declines over time. Recovery rates may be considerably less than 100%. There is lack of reliable low-cost method of monitoring performance. The use of such a process because of the high cost of membranes, low economic value of the product (tertiary effluent) and the potential rapid loss of performance due to membrane fouling. MBR technology require high fluxes, and it was therefore necessary to pump the MLSS at high cross flow velocity at significant energy penalty (of the order 10 kWh/m<sup>3</sup> product) to reduce membrane fouling.<sup>20</sup>

### Applications

**Table 5.1 Applications**

Applications		Description
<b>Aerobic biological treatment</b>		Membrane is used to separate the treated wastewater from the active biomass in an activated-sludge process. The membrane separation unit can be internal immersed in the bioreactor or external to the bioreactor.
<b>Anaerobic biological treatment</b>		Membrane is used to separate the treated wastewater from the active biomass in an anaerobic complete-mix reactor.
<b>Membrane aeration biological treatment</b>		Plate and frame, tubular and hollow membranes are used to transfer pure oxygen to the biomass attached to the outside of the membrane.
<b>Membrane extraction biological treatment</b>		Membranes are used to extract degradable organic molecules from inorganic constituents such as acids, bases and salts from the waste stream for subsequent



*biological treatment.*

**Pretreatment for effective disinfection** *Used to remove residual SS from settled secondary effluent or from the effluent from depth or surface filters to achieve effective disinfection with either chlorine or UV radiation for reuse application.*

**Pretreatment for nanofiltration and reverse osmosis** *Membranes are used to remove residual colloidal and SS as a pretreatment step for additional processing.*

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### ***Angeripalayam (Tiripur, Tamilnadu) CETP based on Membrane Bio Reactor (MBR)***

***Table 5.2 Results of Angeripalayam (Tiripur, Tamilnadu) CETP based on Membrane Bio Reactor***

<b><i>Capacity</i></b>	<b><i>10 MLD</i></b>
<b><i>current discharge</i></b>	<b><i>7.5 MLD</i></b>
<b><i>Inlet COD</i></b>	<b><i>288-850 mg/l</i></b>
<b><i>Inlet BOD</i></b>	<b><i>100-150 mg/l</i></b>
<b><i>Inlet TSS</i></b>	<b><i>100-150 mg/l</i></b>
<b><i>Inlet pH</i></b>	<b><i>7.5-9</i></b>
<b><i>Inlet TDS</i></b>	<b><i>6000 mg/l</i></b>
<b><i>Outlet BOD</i></b>	<b><i>Less than 10mg/l</i></b>
<b><i>Outlet COD</i></b>	<b><i>50-70 mg/l</i></b>
<b><i>Effluent Type</i></b>	<b><i>Effluent from chemical industry</i></b>



*Figure 5.12 Membrane Bio Reactor installed at Angeripalayam (Tiripur, Tamilnadu) CETP*



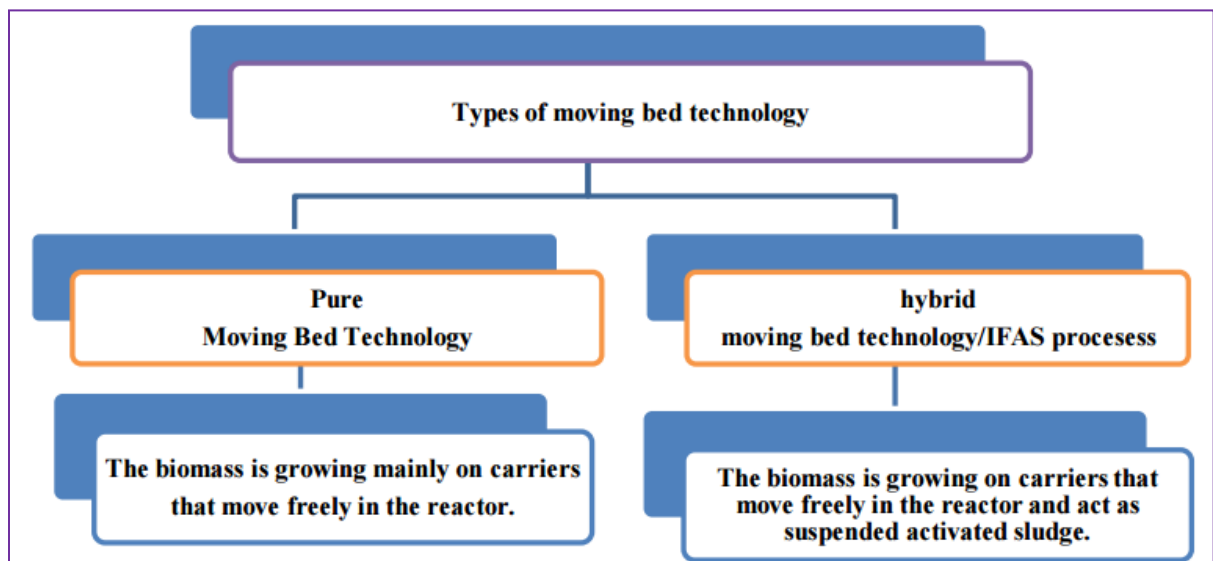
**Figure 5.13 Another View of the MBR at Angeripalayam CETP**

*Figure 5.13 Another view of Membrane Bio Reactor installed at Angeripalayam (Tiripur, Tamilnadu) CETP*

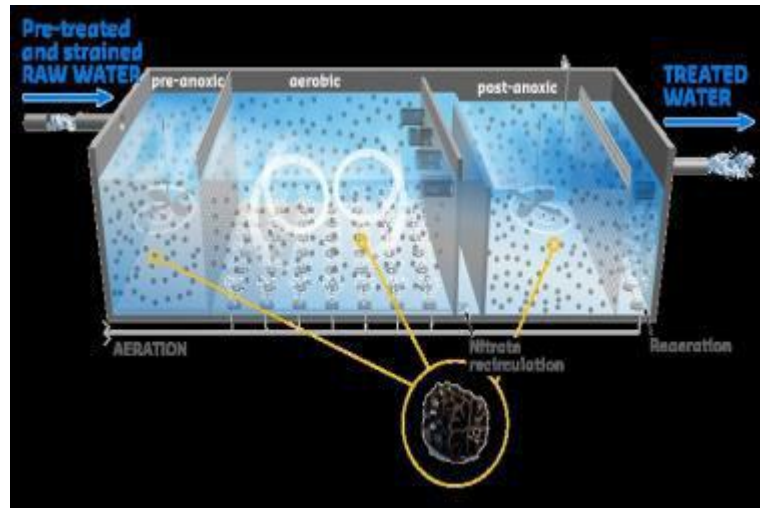
## (6) Moving Bed Biological Reactor (MBBR)

### Description

The Moving Bed Biological Reactor (MBBR) is a highly effective biological treatment process, developed on the basis of conventional activated sludge process and bio-filter process. It is a completely mixed and continuously operated Biological Reactor, where the biomass is grown on small carrier elements that have a little lighter density than water and are kept in movement along with a water stream inside the reactor. The movement inside a reactor can be caused by aeration in an aerobic reactor and by a mechanical stirrer in an anaerobic or anoxic reactor. It is most effective for the treatment of many industrial effluents including pulp and paper industry waste, poultry processing wastewater, cheese factory wastes, refinery and slaughter house waste, phenolic wastewater, dairy wastewater and municipal wastewater. Moreover, as the carrier using in the MBBR is playing a crucial role in system performance, choosing the most efficient carrier could enhance the MBBR performance.



## Working of MBBR



**Figure 6.1 Moving Bed Biofilm Reactor experimental setup**

The MBBR process uses floating plastic carriers (media) within the aeration tank to increase the amount of microorganisms available to treat the wastewater compared to conventional secondary treatment. The microorganisms consume organic material. The media provides increased surface area for the biological microorganisms to attach to and grow in the aeration tanks. The increased surface area reduces the footprint of the tanks required to treat the wastewater. As shown in figure 6.1, the media will be continuously agitated by bubbles from the aeration system that adds oxygen at the bottom of the first compartment of the aeration tank. The microorganisms consume organic material. The middle compartment will contain a channel of stones. The bottom portion of channel will contain large sized stones and upper channel will be of small sized stones. The waste water will be filtered through stone bed to some extent. After filtering, it will enter to last compartment through the openings provided in the setup. In last portion of tank where the bio carriers will be filled, turbulence will be provided to waste water with the help of rotors. After treatment, final treated effluent will be taken outside through outlet.

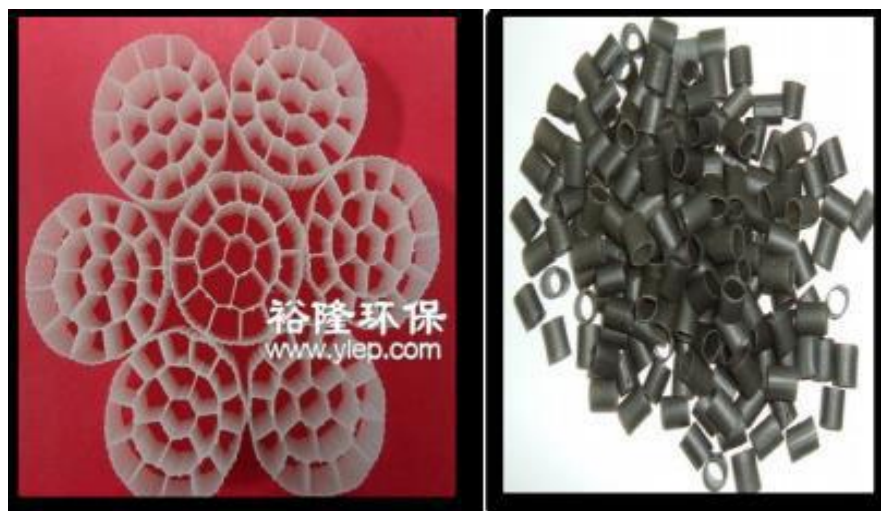


Figure 6.2 Biomedia

Table 6.1 Characteristics of the biomedia

<i>Material</i>	<i>Polypropylene, plastic, ceramic, porous</i>
<i>Shape</i>	<i>Corrugated cylinder, chips, hollow, curved</i>
<i>Density</i>	<i>0.95 g cm<sup>-3</sup></i>
<i>Dimensions</i>	<i>10×15 mm</i>
<i>Specific surface</i>	<i>260 m<sup>2</sup> m<sup>-3</sup></i>

### Operating Principle:

The basic principal of the moving bed process is the growth of the biomass on plastic supports that move in the biological reactor via agitation generated by aeration systems (aerobic reactors) or by mechanical systems (in anoxic or anaerobic reactors). The moving bed processes come from the current trend in wastewater treatment, from the use of systems that offer an increased specific surface in the reactor for the growth of the biomass, achieving significant reductions in the biological reactor volume. Reactor can be operated at very high load and the process is insensitive to load variations and other disturbances.



### Expected Result

Today the need for clean water is rapidly increasing. So MBBR is technology used in the world to treating different kinds of effluents under different conditions because the idea of the MBBR is to combine the two different processes (attached and suspended biomass). The MBBR may help to check the feasibility of waste water treatment by using both attached growth system and suspended growth system.<sup>22</sup>

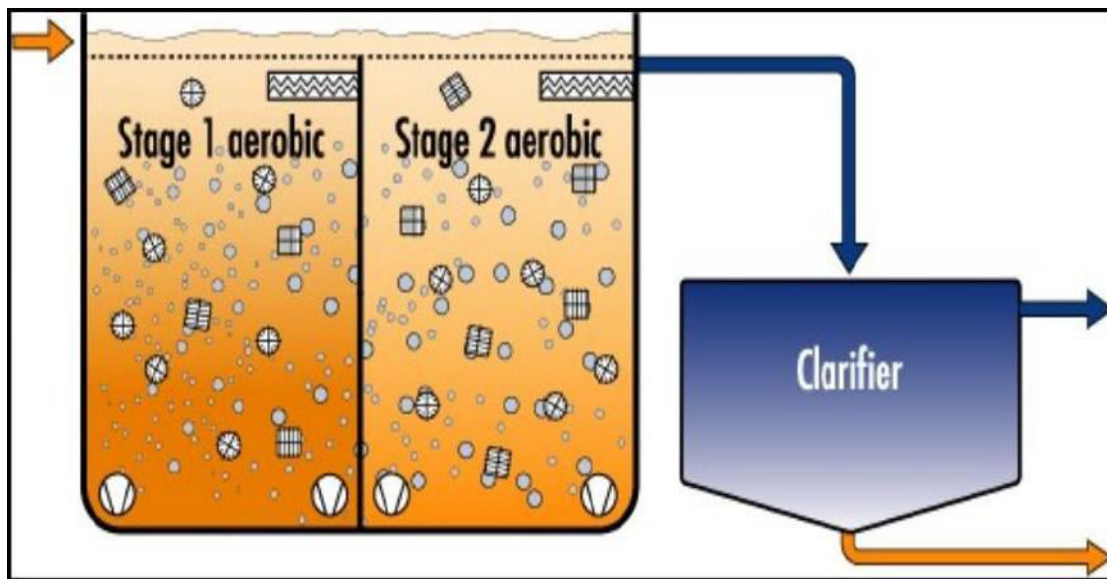
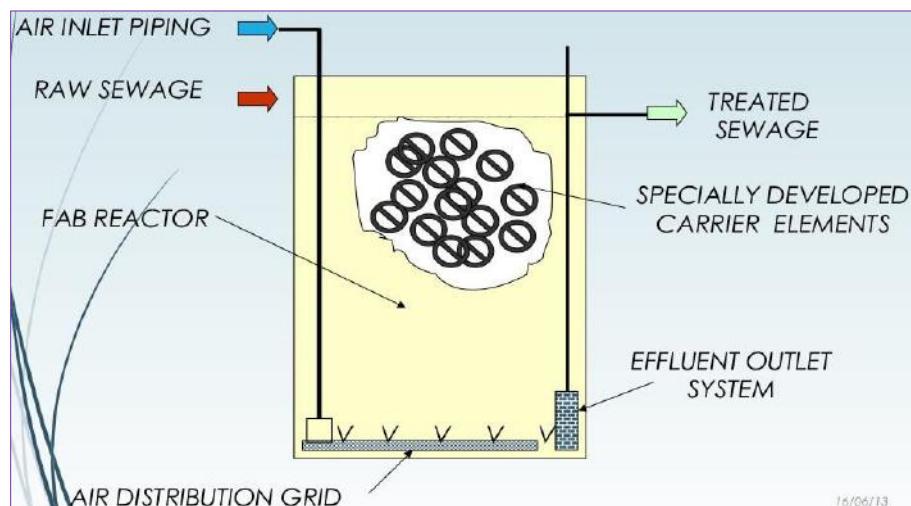
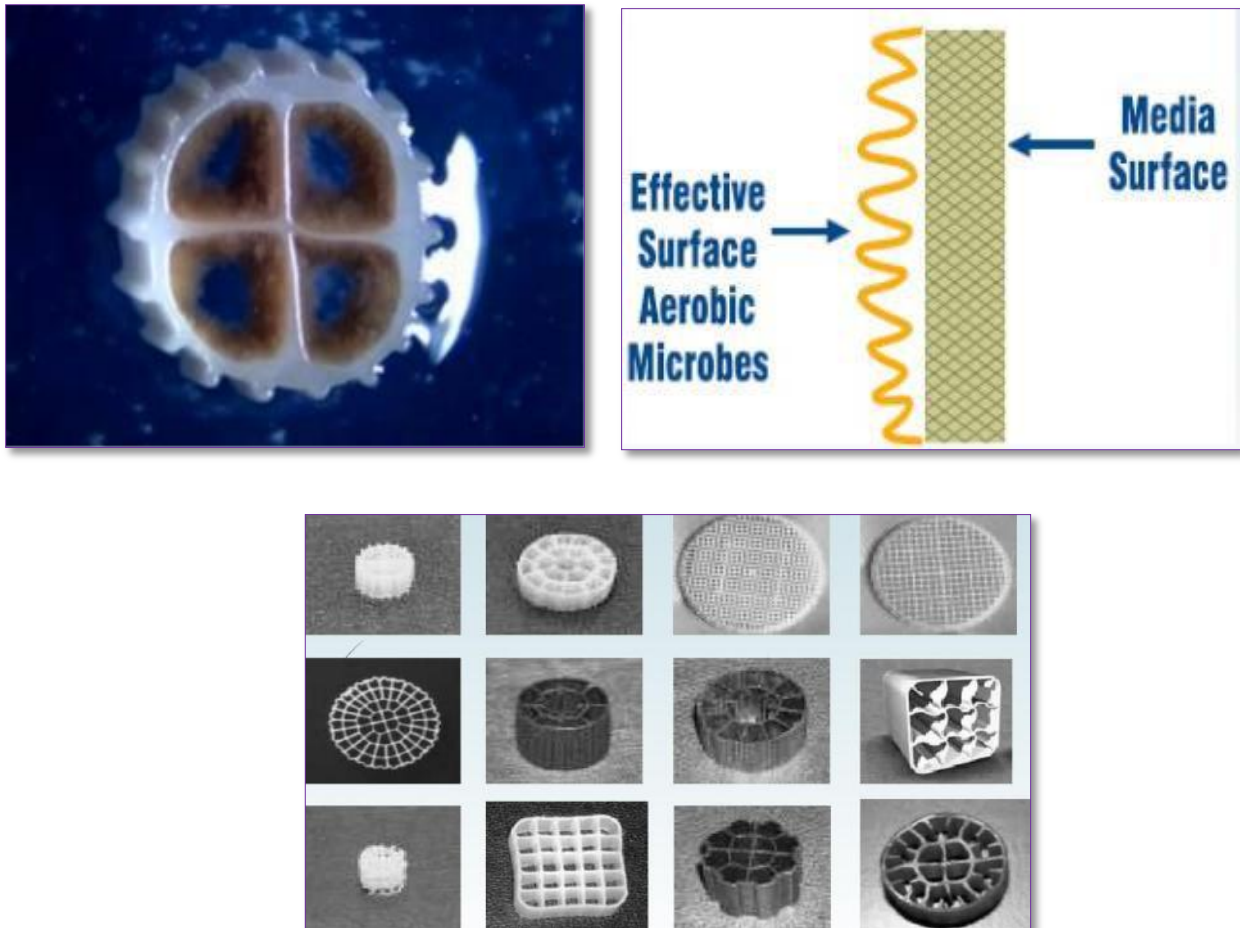


Figure 6.3 Moving Bed Biological Reactor



## Bio carriers



**Figure 6.4 Various Types of Bio carriers Used**

- Carriers occupy 25.70% of tank Volume
- Specific surface area of carrier is about  $500 \text{ m}^2/\text{m}^3$ .
- The carriers are slightly buoyant & have a specific gravity between  $0.94$  &  $0.96 \text{ g/cm}^3$ .
- Media carrier life is around 15 – 20 years

**SSA (Specific Surface area of the reactor) = Surface area of the biofilm on the carrier + The Reactor Volume**

**Design Consideration:****(1) Adequate preliminary treatment**

- To prevent plastic biofilm carrier retention screen blinding.
- To prevent the accumulation of inert material in MBBR tank

**(2) Well designed Aeration System**

- Diffused aeration is used for aerobic MBBR tank ( coarse bubble diffuser )
- Typical oxygen transfer rate = 2.5-3.5 % per meter of water submergence
- Typical air flow rate = 6 to 8 m<sup>3</sup>/m<sup>2</sup>.hr

**(3) Media carrier retention screens**

- Scum must be removed from the system
- Typical screen design allows for a maximum 50 to 150 mm head loss
- Length: Width = 0.5 : 1, 1 : 5.1
- Ratio more than above results in non uniform distribution of bio-carriers
- Biofilm thickness is controlled by air flow or mechanical mixing energy
- Maximum Rate MBBR typically designed for OLR = 5 – 10 g BOD<sub>5</sub>/m<sup>3</sup>.day
- High rate OLR = 40 – 60 Gbod<sub>5</sub>/m<sup>2</sup>.day @ 25<sup>0</sup>C
- Low rate MBBR promote nitrification

**Advantages**

The MBBR is a complete mix, continuous flow through process which combines the advantage of fixed film and suspended growth processes, this advantage includes:

1. Compact units with small size.

2. *Increased treatment capacity.*
3. *Complete solids removal.*
4. *Improved settling characteristics.*
5. *Operation at higher suspended biomass*
6. *Concentrations resulting in long sludge retention times.*
7. *Enhanced process stability.*
8. *Low head loss.*
9. *No filter channeling.*
10. *No need of periodic backwashing.*
11. *Reduced sludge production and no problems with Sludge bulking.*

### ***Application***

1. *Handle high loads sewage*
2. *Improve treatment quality standard*
3. *Also used in Sewage Treatment Plant*
4. *Treated water can be reused*
5. *River water treatment: Denitrification, Dephosphorization*
6. *Remove ammonia- nitrogen for water purification<sup>23</sup>*

## (7) Wet Air Oxidation (WAO)

### Description

The treatment of aqueous industrial process waste effluents is an important and necessary process, with numerous techniques employed. WAO is one of the available technologies for the treatment of aqueous wastewaters. In wet air oxidation aqueous waste is oxidized in the liquid phase at **high temperatures (400–573 K) and pressures (0.5–20 MPa) in the presence** of an oxygen-containing gas (usually air). This technology includes methods to improve mass transfer as well as the use of both homogeneous and heterogeneous catalysts to enhance reaction rate. WAO is a hydrothermal process suitable for the oxidation of organic and inorganic components or pollutants in aqueous waste streams. High temperature and elevated pressure are required, typically operated within the superheated water range (<300 °C, <20 MPa). Generally, the higher the temperature, the higher the level of oxidation achieved, and the associated application of pressure is necessary to maintain the liquid state. Oxygen partial pressure and residence time are also crucial to the degree of oxidation. Residence times can range from seconds to hours depending upon the nature of the material to be oxidized, and obviously limited to the most difficult components to oxidize when considering complex mixtures such as industrial and municipal waste streams.

### The Chemistry of Wet Air Oxidation

Molecular oxygen dissolved in the aqueous phase reacts with the organic and inorganic constituents, resulting in liquid and off-gas product streams. The organic waste is oxidized to water, CO<sub>2</sub> and short chain carboxylic acids, such as acetic and formic acids, which tend to be refractory to further oxidation at temperatures around 250 °C. Lesser product quantities of aldehydes and alcohols are also known. The yield of the carboxylic acids is known to vary greatly, with typically 5-15% of the total organic carbon (TOC) remaining in this form. Both temperature and use of any catalytic system produce a large effect on the organic acid by-product stream, with some control possible. Furthermore, such acids are biodegradable and are therefore not currently viewed as problematic from an environmental viewpoint. Organic nitrogen is converted to NH<sub>3</sub>, NO<sub>2</sub>, NO<sub>3</sub><sup>-</sup>, or N<sub>2</sub>. If present, the elements phosphorus and sulphur are usually reacted to PO<sub>4</sub><sup>3-</sup> and SO<sub>4</sub><sup>2-</sup> respectively. The off-gas contains N<sub>2</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O and



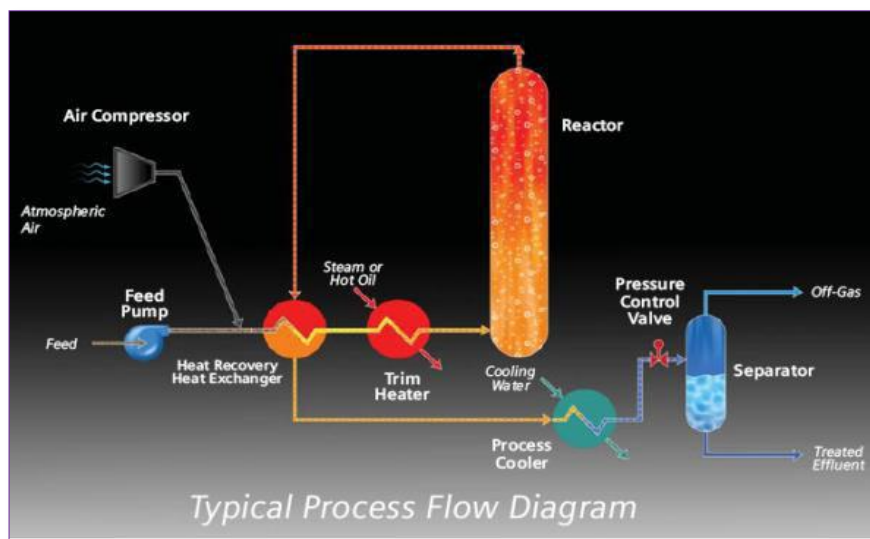
$O_2$ , and possibly  $NH_3$  and other volatile low molecular weight compounds which may be treated by passing through a scrubber column as required. The importance of radicals in the overall oxidation process has naturally led to interest in catalytic systems and promoters in order to overcome thermal limitations, with numerous reviews available.

### Wet Air Oxidation of Wastewater Sludge

In waste water treatment, the primary use of **alum (or alternatively ferric salts)** is as coagulant or as phosphate precipitant, via formation of insoluble aluminium phosphate. Alum and phosphates may therefore be separated from the liquid aqueous stream by WAO providing a significant economic benefit to this process. The organic component of the sludge is significant in terms of proportion and overall quantity and, amongst other criteria, is necessary to be removed from the aqueous stream. Analysis of COD provides a suitable measure of the organic content. A primary benefit of this technique is a significant reduction in COD of the liquid output.<sup>24</sup>

### WAO Process

As we know that Wet air oxidation is the oxidation of soluble or suspended components in water using oxygen as the oxidizing agent.



**Figure 7.1 Typical Process Flow Diagram of Wet Air Oxidation Process**

When air is used as the source of oxygen the process is referred to as wet air oxidation (WAO). The oxidation reactions occur at temperatures of  $150^{\circ}C$  to  $320^{\circ}C$  ( $275^{\circ}F$  to  $608^{\circ}F$ ) and pressures from 10

to 220 bar. The wet oxidation process can pretreat difficult wastewater streams, making them amenable for discharge to a conventional biological treatment plant for polishing. The process is also used for oxidation of contaminants in production liquors for recycle/reuse.<sup>25</sup>

### ***Features & Benefits***

- *Pretreatment of high strength wastewater to produce biodegradable residual organics*
- *Destruction of specific compounds*
- *Elimination of toxicity or reactivity*
- *Process liquor treatment for recycle/recovery*
- *Gross reduction of Chemical Oxygen Demand (COD)*
- *Low operating costs and minimal air pollution discharges.*

### ***Disadvantages***

- *The high capital costs*
- *Safety implications associated with a system operating at such severe operating conditions*
- *In the design of the process a balance must therefore be made between the enhancement of overall reaction rates with temperature and pressure against their effect on capital cost and operational difficulties such as corrosion and scaling of equipment.*

### ***Application***

- *Treatment of high strength wastewater, including spent caustic streams generated by ethylene crackers and refineries*
- *In-process, for treatment and recycle/recovery of process liquor streams*
- *Biological sludge conditioning and destruction*

*Wet oxidation has historically been used for municipal wastewater sludge applications. At lower temperatures and pressures, sludge is conditioned to improve dewatering. This is referred to as Low Pressure Oxidation (LPO). At higher temperatures and pressures, biological sludge can be destroyed, as an alternative to incineration.*

## (8) Ozonation

### Description

Ozone is an unstable gas comprising of three oxygen atoms, the gas will readily degrade back to oxygen, and during this transition a free oxygen atom, or free radical form. The free oxygen radical is highly reactive and short lived; under normal conditions it will only survive for milliseconds. Ozone is a colorless gas that has an odor similar to the smell of the air after a major thunderstorm.

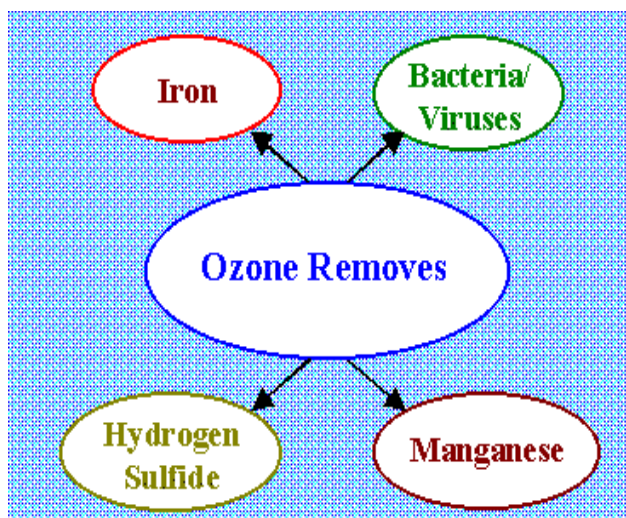


Figure 8.1

Ozone has greater disinfection effectiveness against bacteria and viruses compared to chlorination. In addition, the oxidizing properties can also reduce the concentration of iron, manganese, sulfur and reduce or eliminate taste and odor problems. Ozone oxidizes the iron, manganese, and sulfur in the water to form insoluble metal oxides or elemental sulfur. These insoluble particles are then removed by post-filtration. Organic particles and chemicals will be eliminated through either coagulation or chemical oxidation. Ozone is unstable, and it will degrade over a time frame ranging from a few seconds to 30 minutes. The rate of degradation is a function of water chemistry, pH and water temperature.

## ***Procedure for Ozone Generation***

*The formation of ozone from the oxygen occurs with the use of energy. This process is carried out by an electric discharge field as in the CD-type ozone generators (**corona discharge** simulation of the lightning), or by ultraviolet radiation as in UV-type ozone generators (simulation of the ultraviolet rays from the sun). In addition to these commercial methods, ozone may also be made through electrolytic and chemical reactions. In general, an ozonation system includes **passing dry, clean air through a high voltage electric discharge, i.e., corona discharge**, which creates and ozone concentration of approximately 1% or 10,000 mg/L. In treating small quantities of waste, the UV ozonation is the most common while large-scale systems use either corona discharge or other bulk ozone-producing methods. The raw water is then passed through a venturi throat which creates a vacuum and pulls the ozone gas into the water or the air is then bubbled up through the water being treated. Since the ozone will react with metals to create insoluble metal oxides, post filtration is required.<sup>26</sup>*

### ***Why Ozone is used in waste water treatment?***

- *Powerful disinfectant*
- *No residual (compared to chlorine)*
- *Stronger oxidant (compared chlorine/UV)*

## ***How Ozonation helps in waste water treatment?***

### ***1. Colour Removal:***

*Surface waters are generally colored by natural organic materials such as humic, fulvic and tannic acids. These compounds result from the decay of vegetative materials and are generally related to condensation products of phenol like compounds; they have conjugated carbon/carbon double bonds. When the series of double bonds extend upwards of twenty, the color absorption shows up in the visible spectrum. Ozone is attracted to break organic double bonds. As more of these double bonds are eliminated, the color disappears. Surface water can usually be decolorized when treated with 2 to 4 ppm of Ozone.*

### ***2. Removal of Heavy Metals:***

*Ozone oxidizes the transition metals to their higher oxidation state in which they usually form less soluble oxides, easy to separate by filtration. e.g. iron is usually in the ferrous state when it is dissolved*

in water. With ozone it yields ferric iron, further oxidized in water to Ferric Hydroxide that is very insoluble and precipitates out for filtration. Other metals: Arsenic (in presence of Iron), Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Nickel, Zinc - can be treated in a similar way. At Ozone levels above 4 ppm however, Manganese will form soluble permanganate, showing up as a pink color.

### **3. Improved Coagulation & Turbidity Removal:**

Oxidation of dissolved organic materials by Ozone results in polar and charged molecules that can react with Polyvalent Aluminum or Calcium to form precipitates. Treatment of a surface water with up to 0.5 ppm of Ozone results in a decrease in turbidity, improved settle ability and a reduction in the number of particles. Referred to as preozonation this treatment destabilizes the colloid with a resultant reduction of the amount of coagulant needed to produce a clear filtrate.

### **4. Algae Removal:**

Ozonation of water contaminated with Algae oxidizes and floats the Algae to the top of the reservoir. The ozone will also oxidize the metabolic by-products of the Algae and remove the undesirable odor and taste.<sup>27</sup>



**Figure 8.2 Waste water Ozone Generators and ozonators**



### **Advantages**

1. *Ozone is effective over a wide pH range and rapidly reacts with bacteria, viruses, and protozoans and has stronger germicidal properties than chlorination. Has a very strong oxidizing power with a short reaction time.*
2. *The treatment process does not add chemicals to the water.*
3. *Ozone can eliminate a wide variety of inorganic, organic and microbiological problems and taste and odor problems. The microbiological agents include bacteria, viruses, and protozoans (such as Giardia and Cryptosporidium).*
4. *Ozonation is effective against a large variety of water treatment problems. In general, the more problems in the water to be treated with ozone, the less an ozonation system costs when compared to other traditional treatment methods. When comparing the ECONOMIES cost of an ozonation system with other treatment systems there are some key factors to consider; here are a few:*
  - ✓ *There is no need to purchase, ship or store chemical oxidants or disinfectants*
  - ✓ *There is no need of labor for handling.*
  - ✓ *Many health and safety concerns are reduced or eliminated.*

### **Disadvantages**

1. *There is higher equipment and operational costs and it may be more difficult to find professional proficient in ozone treatment and system maintenance.*
2. *Ozonation provides no germicidal or disinfection residual to inhibit or prevent regrowth.*
3. *Ozonation by-products are still being evaluated and it is possible that some by-products may be carcinogenic. These may include brominated by-products, aldehydes, ketones, and carboxylic acids. This is one reason that the post-filtration system may include an activated carbon filter.*
4. *The system may require pretreatment for hardness reduction or the addition of polyphosphate preventing the formation of carbonate scale.*

5. *Ozone is less soluble in water, compared to chlorine, and, therefore, special mixing techniques are needed.*
6. *Potential fire hazards and toxicity issues associated with ozone generation.*

### ***Applications of Ozonation in Waste Water***

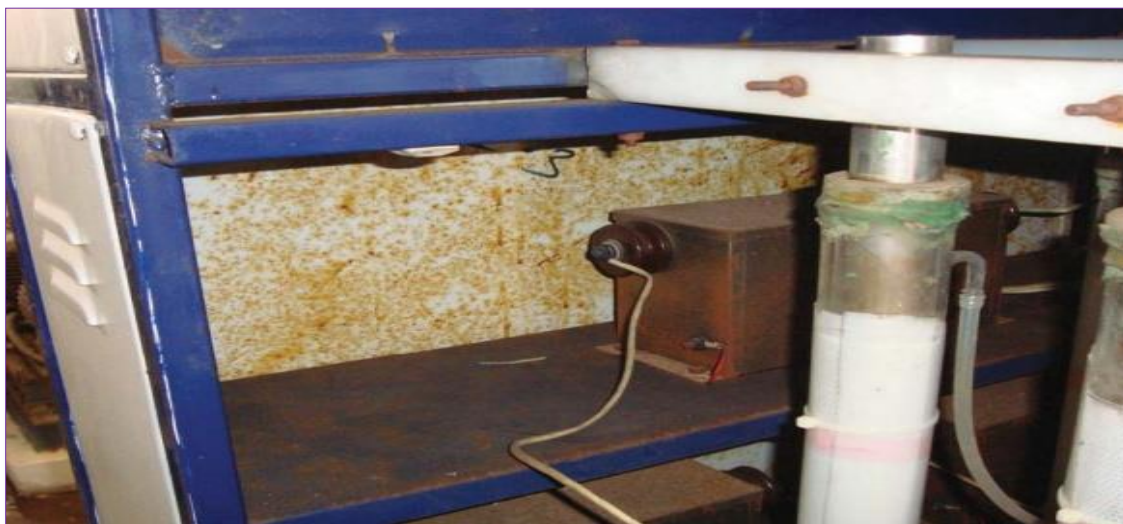
- ✓ *Oxidation of organic waste.*
- ✓ *Cyanide destruction.*
- ✓ *Ground water petrochemical oxidation.*
- ✓ *Heavy metal precipitation.*
- ✓ *Pulp & paper effluents.*
- ✓ *Textile Mill effluents.*
- ✓ *Textile Dye, Starch, FOG (Fate, Oil, Grease) elimination.*
- ✓ *Pesticide, herbicide and insecticide elimination.*
- ✓ *BOD reduction of domestic waste.*
- ✓ *Secondary treatments for municipal waste water.*
- ✓ *Mining heavy metal precipitation*

### ***Ozonation Technology installed at M/s Sri Vidya Industries, Erode. Tamilnadu***

<b><i>Capacity</i></b>	<i>20 MLD</i>
<b><i>Effluent Type</i></b>	<i>Effluent from dying &amp; bleaching unit</i>



*Figure 8.3: Inside View of an Ozonator (Supplied by Shivasu) installed at M/s Sri Vidya Industries, Erode*



*Figure 8.4: Another View of Ozonator installed at M/s Sri Vidya Industries, Erode<sup>28</sup>*

## (9) ELECTROCOAGULATION

### *Description*

*Electrocoagulation is the process of passing of the electrical current through water and it has proven very effective in the removal of contaminants from water. Electrocoagulation technology uses a variety of anode and cathode geometries, such as plates, balls, fluidized bed spheres, wire mesh, rods, and tubes. Although the electrocoagulation mechanism resembles the chemical coagulation - the cationic species being responsible for the neutralization of surface charges – in many ways it is very different. Electrocoagulation is a process of destabilizing suspended, emulsified or dissolved contaminants in an aqueous medium by introducing electrical current into the medium. The electrical current provides the electromotive force causing the chemical reactions.*

***Electrocoagulation induced pH typically shifts towards neutral.***

*The principal cathodic reaction is the reduction of hydrogen ions to hydrogen gas ( $2H^+ + 2e^- = H_2$ ). The principal anodic reaction is the release of metal ions into solution (eg.  $3Al = Al^{3+} + 3e^-$ ). The anodes are sacrificed during the process. The wastewater passes through a chamber with the cathodes and anodes. The electrical current is introduced via parallel plates constructed of metals selected to optimize the removal process. The two most common plate materials are **iron and aluminium**. In accordance with the Faraday's Law, the metal electrodes are sacrificed and slowly dissolve into the liquid medium. The metal ions tend to form metal oxides that electromechanically attract the destabilized contaminants. Anode materials (iron, aluminium), spacing and lengths, applied amperage, voltage and waste water characteristics (pH, standard redox potential, conductivity) can be varied and optimized for maximum removal efficiencies of specific contaminants. The polarity of the electrodes can be reversed periodically to assist in cleaning of the electrodes. After the treated wastewater leaves the electrocoagulation chamber, the destabilized colloids are allowed to flocculate and then separated in an integrated system. The sludge can be further de-watered using a filter press, settling pond, or other de-watering techniques.*

***System capabilities:***

- *Removes heavy metals;*
- *Removes suspended and colloidal solids;*
- *Destabilizes oil and other emulsions;*
- *Removes fats, oils and grease;*
- *Removes complex organics; and*
- *Destroys and removes bacteria, viruses and cysts.*

***Advantages***

- *Treats multiple contaminants;*
- *Sludge minimization;*
- *Capital cost significantly less than conservative technologies;*
- *Operating cost significantly less than conservative technologies;*
- *Low power requirements;*
- *Generally no chemical additions;*
- *Low maintenance;*
- *Minimal operator attention; and*
- *Consistent and reliable results.*

***Electrocoagulation – performance and operation******Description of the EC unit:***

*The diagram in as shown in Figure 9.1 represents the schematic of the general electrocoagulation process. A typical system includes: a feeding tank (1); the reaction chamber with electrodes (2); a development tank (3) where the reactions initialized within the reaction chamber; and a sludge separation unit (4), specific to various types of effluent treated.*

***Operation of the EC plant:***

*The mode of operating of the unit is very much based on the operators experience with the particular type of wastewater. The operator has to be able to assess the quality of the floc produced and set the*



variables (amperage, voltage, electrode material, flow) accordingly to produce the best results. Once working with wastewater of reasonably known and constantly uniform nature, the unit is set in a particular way and would operate automatically, without the need of constant attention. The technology is able to accommodate certain level of wastewater parameter variations and still treat the effluent adequately, but a considerable difference in the incoming flow requires the operator's attention and modifications to the setting of the machine.<sup>29</sup>

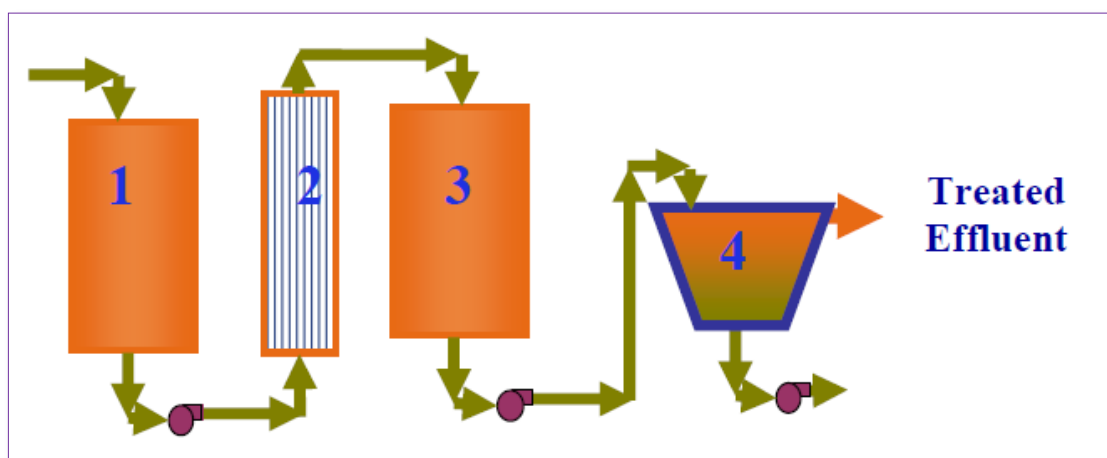


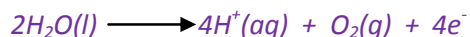
Figure 9.1 EC unit schematic flow sheet

### Theory of Electrocoagulation

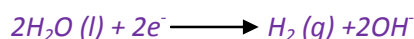
During EC, cations are generated by dissolution of sacrificial anodes with applied electrical field which induce flocculation of the dispersed impurities, by reducing the zeta potential of the suspended matters. The metal hydroxide formed coagulates the liquid impurities, and the hydrogen bubbles evolved at the cathode permit the flotation of foam containing the organic matter. The aggregates formed can be removed by settling or flotation. The potential of the cathode is in the region where  $\text{Fe(III)}$  is reduced to  $\text{Fe(II)}$  form and therefore, both forms exist in the EC system. The generation of iron hydroxides  $\text{Fe(OH)}_n$  is followed by an electrophoretic concentration of colloids in the portion close to the anode. The produced ferrous ions hydrolyze to form monomeric hydroxide ions and polymeric hydroxide complexes that is influenced by the pH of the solution. The polymeric hydroxides, which are highly charged cations, destabilize the negatively charged colloidal particles allowing the disaggregation and formation of flocs. It also, depends on the solubility of the metal hydroxide.

## Reactions at Electrodes

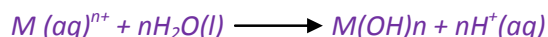
### At anode



### At cathode



### In solution



## Factors affecting Electrocoagulation

There are various parameters which have an effect on the efficiency of the EC in removing the pollutants from raw water or wastewater. Parameters which are influencing EC are:

**A. Material of the electrodes** can be iron, aluminum and/or inert material (cathodes). Optimal material selection depends on the pollutants to be removed and the chemical properties of the electrolyte. In general, aluminum seems to be superior compared to iron in most cases, when only the efficiency of the treatment is considered. However, it should be noted that aluminum is more expensive compared to iron. Inert electrodes, such as metal oxide coated titanium, are used as cathodes in some constructions. When water has significant amounts of calcium or magnesium ions, the inert cathode material is recommended. For COD & phenol removal iron is good and for color and turbidity removal aluminum give better results. If we are using electro-chemically inert materials like stainless steel as cathode, we will get protection from corrosion. Besides SS produce smaller bubbles which possess larger surface area and can remove more impurities through flotation.

**B. pH of the solution** has an effect on the speciation of metal hydroxides in the solution. During electro coagulation the pH of the solution increases due to the contribution of OH<sup>-</sup> ions into the solution and it

enhances the efficiency of the system. Initial pH between 7 to 9 gives better results and if the pH raises beyond 9 the efficiency decreases due to the formation of soluble  $\text{Fe}(\text{OH})_4$  and  $\text{Al}(\text{OH})_4$ . Only insoluble metal hydroxides of iron can remove pollutants by electrostatic attraction. The kinetics of conversion of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  is strongly affected by pH.

**C. Current density** is proportional to the amount of electrochemical reactions taking place on the electrode surface. When current density increases the reaction rate also increases by the more metal ions in solution. But the rapid contribution of metal ions in the system cost more and further increase results in restabilization of metal particles in the solution.

**D. Treatment time** added per volume is proportional to the amount of coagulants produced in EC system and other reactions taking place in the system. Efficiency increases with increase in electrolysis time. But if we increase the electrolysis time beyond some extend the removal efficiency decreases because of the free metal ions in the solution.

**E. Temperature** affects floc formation, reaction rates and conductivity. Depending on the pollutant, the increasing temperature can have a negative or a positive effect on removal efficiency. Normally better results are obtained at low temperature and higher temperature results in dissolution of metal ions into the solution.

**f. Inter electrode** distance have great importance in EC. Very less electrode distance may cause short circuit and very high distance results in lesser contribution of metal ions into the solution which minimize the efficiency of the system. So it is better to keep this in medium according to the characteristics of wastewater.

### **Application, Benefits & Drawbacks of EC**

EC has ability to treat wide range of pollutants heavy metals, foodstuff, oil, textile dyes, fluorine, polymeric wastes, organic matter from landfill leachate, suspended particles, chemical and mechanical polishing wastes, aqueous suspensions of ultrafine particles, nitrate, phenolic waste, arsenic, refractory organic pollutants including lignin and EDTA etc from Industrial and domestic wastewater by using simple and compact equipments. Practically no chemical addition is required in this process; it brings minimum chance of secondary pollution with lesser operating costs and maintenance. Although EC has many advantages it has its own disadvantages. It requires a minimum conductivity depending on reactor

*design. The 'sacrificial anodes need to be replaced periodically. Wastewater with high humic and fluvic acid content may be amenable to the formation of trihalomethanes. An impermeable oxide film may be formed on the cathode that may interfere with the performance of the EC cell and the cost of operating EC may be high in those areas where the cost of electricity is high.*

## **Conclusion**

*Electro-coagulation is a simple technology with compact design. The main demerit of the system is need of electric current as energy source. But it can be overcome by use of renewable resources like solar energy. There is no particular design criteria for the reactor design, but we can keep a ratio between current density and Surface area of electrode to volume of electrolyte for getting finest results. Stainless steel electrode in the form of anode give smaller bubbles which can enhance flotation with compared to larger bubbles. Also usage of electrochemically inert materials as cathode reduces the chance of rusting of electrodes. Furthermore the one of the main parameter affects the treatment efficiency of the system is pH of the solution, so for better results it is recommended to keep the pH of the solution on between 7-9.<sup>30</sup>*

## (10) Fenton's Reagent Oxidation

### Description

Fenton technology is one of the Advanced Oxidation Process (AOPs) that widely used to treat the wastes that not easy to decompose. This Fenton reaction involves producing of very effective oxidation agent in the removal of organic compound in the wastewater. Besides that, this process is cheaper, easier and suitable in application of treatment of various type of wastewater. Another method like UV, ozone and others are identified increasing the cost in treatment of wastewater. Fenton uses catalyst ions and hydrogen peroxide, most of organic compound easy to oxidize. This technology does not need high pressure and high temperature. It also does not complex equipment. Fenton mechanism involve hydroxyl radical ( $\text{OH}^\bullet$ ) that produce from decomposition of  $\text{H}_2\text{O}_2$ . Fenton reagent can remove COD parameter about 89% and can remove  $\text{BOD}_5$  more than 95% and suspended solid until 97%. Fenton reaction wastewater treatment technology is known to be very effective in the removal of many hazardous organic pollutants from water.

### Theory of Fenton Process:

As we know that Fenton process requires the usage of hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) as the oxidation agents. However, hydrogen peroxide alone is still not enough to conclude the reaction because of high concentration of certain refractory contaminants and the low rate of reactions at reasonable  $\text{H}_2\text{O}_2$  concentration. There is reaction between  $\text{H}_2\text{O}_2$  and iron (metal) salts carried out and it will result in the formation of hydroxyl radicals,  $\text{HO}^\bullet$ .

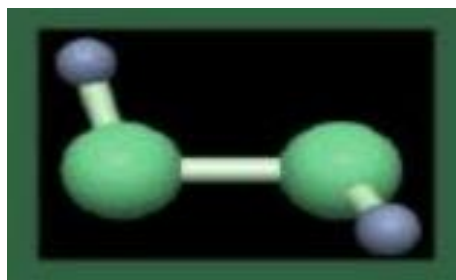


Figure 10.1 Hydrogen Peroxide Molecule.



*This advanced oxidation techniques with the presence of  $HO^\bullet$ , will nonspecifically oxidize target compounds at high reaction rates.*

### ***Oxidation by Fenton process***

*In aqueous solution, hydrogen peroxide used as the oxidation reagents then produce hydroxyl radicals,  $OH^\bullet$  and oxidize the  $Fe^{2+}$  ions into  $Fe^{3+}$ . The Fenton reaction causes the dissociation of the oxidant and the formation of highly reactive hydroxyl radicals that attack and destroy the organic pollutants.*



### ***Kinetic Schemes***

*As above shown, Fenton's reagent is a mixture of  $H_2O_2$  and ferrous iron, which generates hydroxyl radicals according to the reaction.*



*Moreover, the newly formed ferric ions may catalyse hydrogen peroxide, causing it to be decomposed into water and oxygen. Ferrous ions and radicals are also formed in the reactions. The reactions are as shown in Equations (3) – (7).*



*The reaction of hydrogen peroxide with ferric ions is referred to as a Fenton-like reaction*



As seen in reaction (7),  $H_2O_2$  can act as an  $OH^\bullet$  scavenger as well as an initiator [reaction (1)]. Hydroxyl radicals can oxidise organics (RH) by abstraction of protons producing organic radicals ( $R^\bullet$ ), which are highly reactive and can be further oxidized.



If the concentrations of reactants are not limiting, the organics can be completely detoxified by full conversion to  $CO_2$ , water and in the case of substituted organics, inorganic salts if the treatment is continued.



This equation suggests that the presence of  $H^+$  is required in the decomposition of  $H_2O_2$ , indicating the need for an acid environment to produce the maximum amount of hydroxyl radicals. In the presence of organic substrates (RH), excess ferrous ion, and at low pH, hydroxyl radicals can add to the aromatic or heterocyclic rings (as well as to the unsaturated bonds of alkenes or alkynes). They can also abstract a hydrogen atom, initiating a radical chain oxidation.



The organic free radicals produced in reaction (10) may then be oxidized by  $Fe^{3+}$ , reduced by  $Fe^{2+}$ , or dimerised according to the following reactions.



The sequence of reactions (1), (2), (10) and (13) constitute the present accepted scheme for the Fenton's reagent chain. The ferrous ions generated in the above redox reactions (8) and (9) react with hydroxide ions to form ferric hydroxo complexes.





Within pH 3 and 7, the above complexes become



This accounts for the coagulation capability of Fenton's reagent. Dissolved suspended solids are captured and precipitated. It should be noted that large amounts of small flocs are consistently observed in the Fenton oxidation step. Those flocs take a very long time to settle but can be precipitated after that.

This Fenton oxidation reaction depends on the stoichiometric relationship. The key features of the Fenton system are believed to be its reagent conditions, i.e.  $[\text{Fe}^{2+}]$ ,  $[\text{Fe}^{3+}]$ ,  $[\text{H}_2\text{O}_2]$  and the reaction characteristics (pH, temperature and the quantity of organic and inorganic constituents). Because these parameters determine the overall reaction efficiency, it is important to understand the mutual relationships between these parameters in terms of hydroxyl radical production and consumption. High ratio of  $[\text{Fe}^{2+}]/[\text{H}_2\text{O}_2]$  ( $\geq 2$ ), medium ratio of  $[\text{Fe}^{2+}]/[\text{H}_2\text{O}_2]$  ( $=1$ ), and low ratio of  $[\text{Fe}^{2+}]/[\text{H}_2\text{O}_2]$  ( $<1$ ) are the three conditions that we must take into account for.<sup>31</sup>

### **The procedure requires:**

- Adjusting the wastewater to pH 3-5
- Adding the iron catalyst (as a solution of  $\text{FeSO}_4$ ); and
- Adding slowly the  $\text{H}_2\text{O}_2$ . If the pH is too high, the iron precipitates as  $\text{Fe}(\text{OH})_3$  and catalytically decomposes the  $\text{H}_2\text{O}_2$  to oxygen -- potentially creating a hazardous situation.

Reaction rates with Fenton's Reagent are generally limited by the rate of OH generation (i.e., concentration of iron catalyst) and less so by the specific wastewater being treated. Typical  $\text{Fe}:\text{H}_2\text{O}_2$  ratios are 1:5-10 wt/wt, though iron levels  $< 25\text{-}50\text{ mg/L}$  can require excessive reaction times (10-24 hours). This is particularly true where the oxidation products (organic acids) sequester the iron and remove it from the catalytic cycle. Fenton's Reagent is most effective as a pretreatment tool, where COD's are  $> 500\text{ mg/L}$ . This is due to the loss in selectivity as pollutant levels decrease:

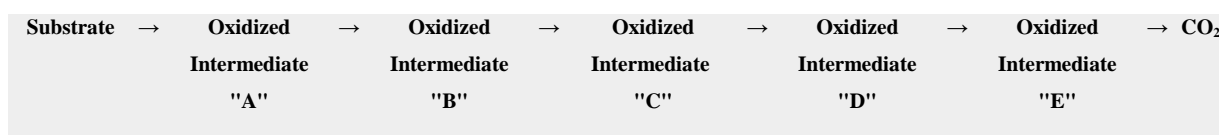
*In addition to free radical scavengers, the process is inhibited by (iron) chelants such as phosphates, EDTA, formaldehyde, and citric/oxalic acids. Because of the sensitivity of Fenton's Reagent to different wastewaters, it is recommended that the reaction always be characterized through laboratory treatability tests before proceeding to plant scale.*

#### ***Effect of Iron Type (Ferrous or Ferric) on reaction efficiency:***

*For most applications, it does not matter whether  $Fe^{2+}$  or  $Fe^{3+}$  salts are used to catalyze the reaction -- the catalytic cycle begins quickly if  $H_2O_2$  and organic material are in abundance. However, if low doses of Fenton's Reagent are being used (e.g., < 10-25 mg/L  $H_2O_2$ ), some research suggests ferrous iron may be preferred. Neither does it matter whether a chloride or sulfate salt of the iron is used, although with the former, chlorine may be generated at high rates of application. It is also possible to recycle the iron. This can be done by raising the pH, separating the iron floc, and re-acidifying the iron sludge. There have been some recent developments in supported catalysts that facilitate iron recovery and reuse.*

#### ***Effect of $H_2O_2$ Concentration on reaction efficiency:***

*Because of the indiscriminate nature by which hydroxyl radicals oxidize organic materials, it is important to profile the reaction in the laboratory for each waste to be treated. For example, in a typical application the following series of reactions will occur:*



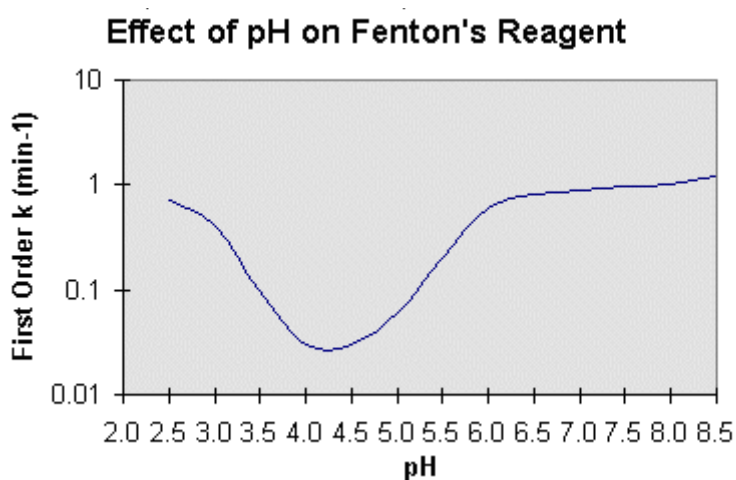
*Each transformation in this series has its own reaction rate and, as the case of phenolics illustrates, there may occur build-up of an undesirable intermediate (quinones), which requires sufficient  $H_2O_2$  to be added to push the reaction beyond that point. This is frequently seen when pretreating a complex organic wastewater for toxicity reduction. As the  $H_2O_2$  dose is increased, a steady reduction in COD may occur with little or no change in toxicity until a threshold is attained, whereupon further addition of  $H_2O_2$  results in a rapid decrease in wastewater toxicity.*

**Effect of Temperature on reaction efficiency:**

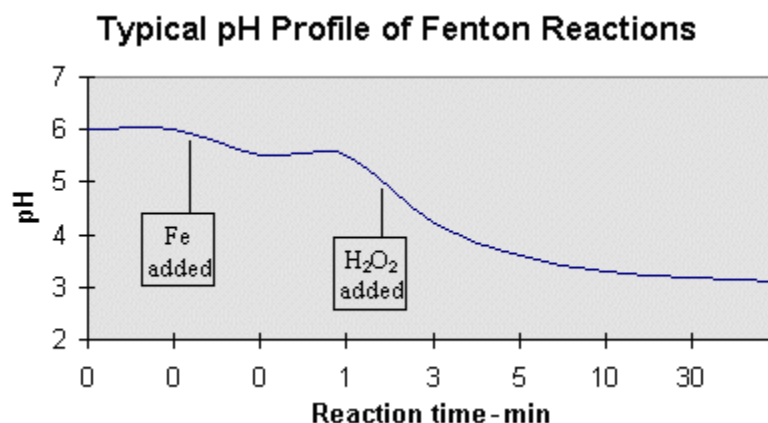
The rate of reaction with Fenton's Reagent increases with increasing temperature, with the effect more pronounced at temperatures  $< 20$  deg-C. However, as temperatures increase above 40-50 deg-C, the efficiency of  $H_2O_2$  utilization declines. This is due to the accelerated decomposition of  $H_2O_2$  into oxygen and water. As a practical matter, most commercial applications of Fenton's Reagent occur at temperatures between 20-40 deg-C.

**Effect of pH on reaction efficiency:**

The effect of pH on reaction efficiency is illustrated below:



The optimal pH occurs between pH 3 and pH 6. The drop in efficiency on the basic side is attributed to the transition of iron from a hydrated ferrous ion to a colloidal ferric species. In the latter form, iron catalytically decomposes the  $H_2O_2$  into oxygen and water, without forming hydroxyl radicals. There have been some recent developments using nonradical scavenging sequestering agents (e.g., NTA and gallic acid) to extend the useful pH range to pH 8-9, but no commercial applications are known. The drop in efficiency on the acid side is less dramatic given the logarithmic function of pH, and is generally a concern only with high application rates. A second aspect of pH deals with its shift as the reaction progresses. Provided an initial wastewater pH of 6.0, the following profile is typical of Fenton reactions.



The first inflection is caused by the addition of  $\text{FeSO}_4$  catalyst which typically contains residual  $\text{H}_2\text{SO}_4$ . A second, more pronounced drop in pH occurs as the  $\text{H}_2\text{O}_2$  is added, and continues gradually at a rate which is largely dependent on catalyst concentration. This drop in pH is attributed to the fragmenting of organic material into organic acids. This pH change is often monitored to ensure that the reaction is progressing as planned -- the absence of such a pH decrease may mean that the reaction is inhibited and that a potentially hazardous build-up of  $\text{H}_2\text{O}_2$  is occurring within the reaction mixture.

In highly concentrated waste streams ( $>10$  g/L COD), it may be necessary to perform the oxidation in steps, readjusting the pH upwards to pH 4-5 after each step so as to prevent low pH from inhibiting the reaction.

#### **Effect of Reaction Time on reaction efficiency:**

The time needed to complete a Fenton reaction will depend on the many variables discussed above, most notably catalyst dose and wastewater strength. For simple phenol oxidation (less than ca. 250 mg/L), typical reaction times are 30 - 60 minutes. For more complex or more concentrated wastes, the reaction may take several hours. In such cases, performing the reaction in steps (adding both iron and  $\text{H}_2\text{O}_2$ ) may be more effective (and safer) than increasing the initial charges.

#### **Effect of Post Treatment on reaction efficiency:**

As a result of degrading complex organic materials into organic acid fragments, the pre-oxidized effluent is generally more amenable to conventional treatment, e.g., flocculation and biotreatment. The presence of iron in the reaction mixture makes it particularly suited to subsequent lime flocculation. In many cases, it may be possible to remove up to 80% of the wastewater COD through a combination of



*Fenton's Reagent and lime flocculation. Significantly, this may be achieved with an  $H_2O_2$  dose of 50-75% of the stoichiometry.*

### ***Process Equipment:***

*This technology can be used in both continuous and sequential batch processes. A typical batch operation would consist of chemical storage and dosing modules (for  $H_2O_2$ ,  $FeSO_4$ , acid, and lime/ $NaOH$ ); a primary reactor and (optional) holding tank; a solids dewatering device (optional); and miscellaneous temperature and pH controls. The materials of construction for the reactor and holding tank are typically Types 304 or 316 stainless steel, while those for the chemical storage systems may also be HDPE. Packaged Fenton's systems are available from some equipment providers, or US Peroxide can provide you with engineering guidance on custom designs and retrofits.<sup>32</sup>*

### ***Advantages***

*Fenton's reagent oxidation was employed for organic matter and color removal, along with biodegradability improvement, of a synthetic acrylic dyeing wastewater, previously treated by coagulation/flocculation. The initial iron load in the Fenton's stage varied from the residual soluble iron concentration resulting from the coagulation/flocculation process (which was 275 mg Fe/L) up to 400 mg/L, by adding increasing amounts of ferrous sulfate. The combination of the two treatments led to overall removals of 99.8, 84.2 and 78.6% for color, dissolved organic carbon (DOC) and chemical oxygen demand (COD), respectively, complying with maximum allowable discharge values. The Fenton process was also directly applied to the effluent. Under the optimum conditions, the color removal (99.5%) was similar to that obtained in the combined process, but DOC and COD removals were lower (66.5 and 65.1%, respectively). An improvement of the wastewater biodegradability was observed in such condition: the specific oxygen uptake rate and BOD:COD ratio increased from <0.2 to 17.9  $mgO_2/(g_{VSS}\cdot h)$  and from ~0 to 0.40, respectively. The effluent toxicity also decreased, from 97 to 29% (30 min contact time), allowing the subsequent integration of a biological process.*

## (11) Sequencing Batch Reactors (SBR)

### Description

SBRs are a variation of the activated-sludge process. They differ from activated-sludge plants because they combine all of the treatment steps and processes into a single basin, or tank, whereas conventional facilities rely on multiple basins.

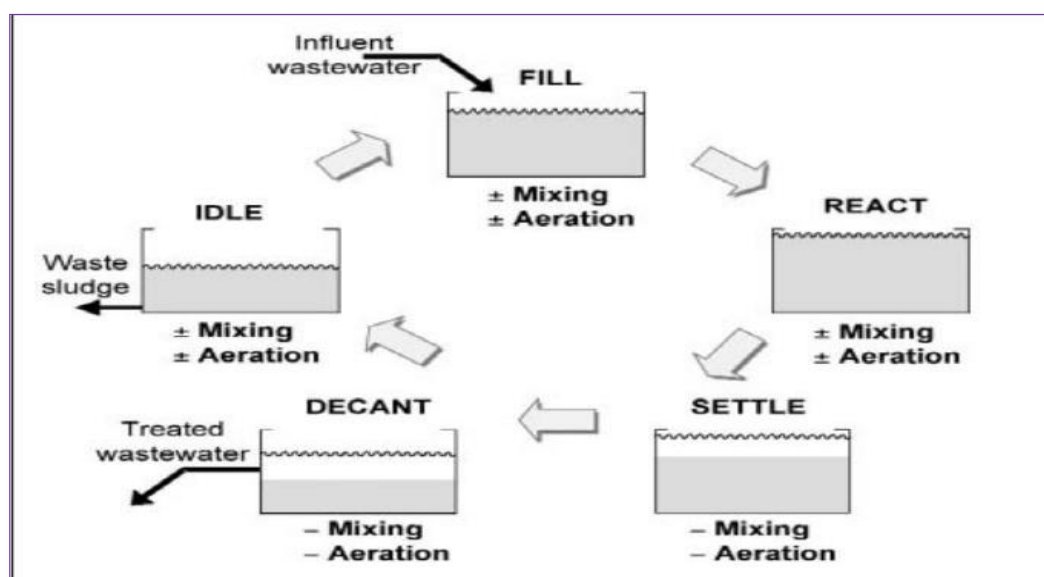


Figure 11.1 MAJOR PHASES OF THE SBR OPERATIONS CYCLE

### Basic Treatment Process

The operation of an SBR is based on a fill-and-draw principle, which consists of five steps—fills, react, settle, decant, and idle. These steps can be altered for different operational applications.

**Fill:** During the fill phase, the basin receives influent wastewater. The influent brings food to the microbes in the activated sludge, creating an environment for biochemical reactions to take place. Mixing and aeration can be varied during the fill phase to create the following three different scenarios:

➤ **Static Fill –**

*Under a static-fill scenario, there is no mixing or aeration while the influent wastewater is entering the tank. Static fill is used during the initial start-up phase of a facility, at plants that do not need to nitrify or denitrify, and during low flow periods to save power. Because the mixers and aerators remain off, this scenario has an energy-savings component.*

➤ **Mixed Fill –**

*Under a mixed-fill scenario, mechanical mixers are active, but the aerators remain off. The mixing action produces a uniform blend of influent wastewater and biomass. Because there is no aeration, an anoxic condition is present, which promotes denitrification. Anaerobic conditions can also be achieved during the mixed-fill phase. Under anaerobic conditions the biomass undergoes a release of phosphorous. This release is reabsorbed by the biomass once aerobic conditions are reestablished. This phosphorous release will not happen with anoxic conditions.*

➤ **Aerated Fill –**

*Under an aerated-fill scenario, both the aerators and the mechanical mixing unit are activated. The contents of the basin are aerated to convert the anoxic or anaerobic zone over to an aerobic zone. No adjustments to the aerated-fill cycle are needed to reduce organics and achieve nitrification. However, to achieve denitrification, it is necessary to switch the oxygen off to promote anoxic conditions for denitrification. By switching the oxygen on and off during this phase with the blowers, oxic and anoxic conditions are created, allowing for nitrification and denitrification. Dissolved oxygen (DO) should be monitored during this phase so it does not go over 0.2 mg/L. This ensures that an anoxic condition will occur during the idle phase.*

**React:** *This phase allows for further reduction or "polishing" of wastewater parameters. During this phase, no wastewater enters the basin and the mechanical mixing and aeration units are on. Because there are no additional volume and organic loadings, the rate of organic removal increases dramatically. Most of the carbonaceous BOD removal occurs in the react phase. Further nitrification occurs by allowing the mixing and aeration to continue—the majority of denitrification takes place in the mixed-fill phase. The phosphorus released during mixed fill, plus some additional phosphorus, is taken up during the react phase.*

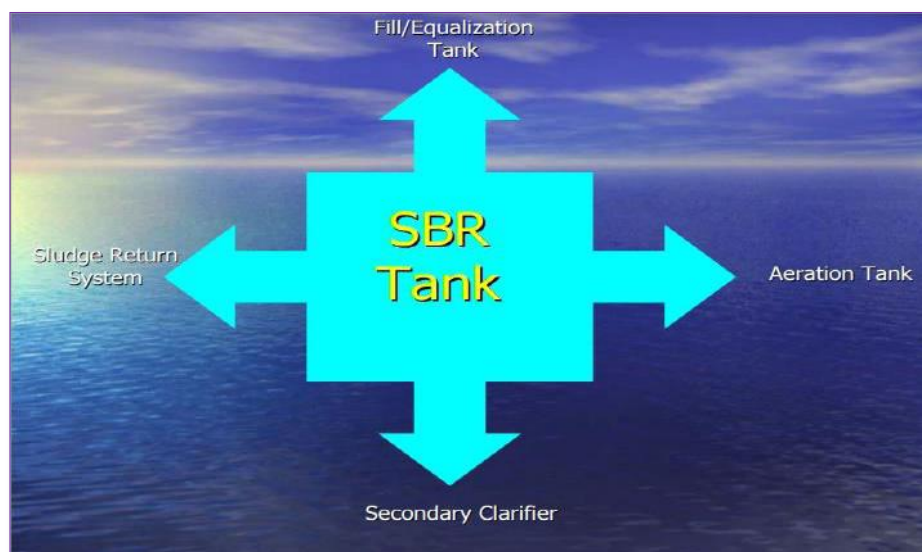
**Settle:** During this phase, activated sludge is allowed to settle under quiescent conditions—no flow enters the basin and no aeration and mixing takes place. The activated sludge tends to settle as a flocculent mass, forming a distinctive interface with the clear supernatant. The sludge mass is called the sludge blanket. This phase is a critical part of the cycle, because if the solids do not settle rapidly, some sludge can be drawn off during the subsequent decant phase and thereby degrade effluent quality.

**Decant:** During this phase, a decanter is used to remove the clear supernatant effluent. Once the settle phase is complete, a signal is sent to the decanter to initiate the opening of an effluent-discharge valve. There are floating and fixed-arm decanters. Floating decanters maintain the inlet orifice slightly below the water surface to minimize the removal of solids in the effluent removed during the decant phase. Floating decanters offer the operator flexibility to vary fill and draw volumes. Fixed-arm decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. It is optimal that the decanted volume is the same as the volume that enters the basin during the fill phase. It is also important that no surface foam or scum is decanted. The vertical distance from the decanter to the bottom of the tank should be maximized to avoid disturbing the settled biomass.

**Idle:** This step occurs between the decant and the fill phases. The time varies, based on the influent flow rate and the operating strategy. During this phase, a small amount of activated sludge at the bottom of the SBR basin is pumped out—a process called wasting.<sup>34</sup>

### Applicability

SBRs are typically used at flow rates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flow rates.



*As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.<sup>35</sup>*

### **Design Criteria**

*Once the influent and effluent characteristics of the system are determined, the engineer will typically consult SBR manufacturers for a recommended design. Based on these parameters, and other site specific parameters such as temperature, key design parameters are selected for the system. An example of these parameters for a wastewater system loading is listed in Table 11.1.*

**Table 11.1 KEY DESIGN PARAMETERS**

<i>Factors</i>	<i>Municipal</i>	<i>Industrial</i>
<i>Food to Mass (F:M)</i>	<i>0.15 - 0.4/day</i>	<i>0.15 - 0.6/day</i>
<i>Treatment Cycle Duration</i>	<i>4.0 hours</i>	<i>4.0 - 24 hours</i>
<i>Typically Low Water Level Mixed Liquor Suspended Solids</i>	<i>2,000-2,500 mg/L</i>	<i>2,000 - 4,000 mg/L</i>
<i>Hydraulic Retention Time</i>	<i>6 - 14 hours</i>	<i>varies</i>

*Once the key design parameters are determined, the number of cycles per day, number of basins, decant volume, reactor size, and detention times can be calculated. Additionally, the aeration equipment, decanter, and associated piping can then be sized. Other site specific information is needed to size the aeration equipment, such as site elevation above mean sea level, wastewater temperature, and total dissolved solids concentration.*

### **Construction**

*Construction of SBR systems can typically require a smaller footprint than conventional activated sludge systems because the SBR often eliminates the need for primary clarifiers. The SBR never requires secondary clarifiers. The size of the SBR tanks themselves will be site specific; however the SBR system*

is advantageous if space is limited at the proposed site. A few case studies are presented in Table 11.2 to provide general sizing estimates at different flow rates. Sizing of these systems is site specific and these case studies do not reflect every system at that size.<sup>36</sup>

**Table 11.2 CASE STUDIES FOR SEVERAL**

<i>Flow</i>	<i>Reactors</i>			<i>Blowers</i>	
<i>(MGD)</i>	<i>No.</i>	<i>Size (feet)</i>	<i>Volume (MG)</i>	<i>No.</i>	<i>Size (HP)</i>
<b>0.012</b>	1	18 x 12	0.021	1	15
<b>0.10</b>	2	24 x 24	0.069	3	7.5
<b>1.2</b>	2	80 x 80	0.908	3	125
<b>1.0</b>	2	58 x 58	0.479	3	40
<b>1.4</b>	2	69 x 69	0.678	3	60
<b>1.46</b>	2	78 x 78	0.910	4	40
<b>2.0</b>	2	82 x 82	0.958	3	75
<b>4.25</b>	4	104 x 80	1.556	5	200
<b>5.2</b>	4	87 x 87	1.359	5	125

### ***Tank and Equipment Description***

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system. The central features of the SBR system include the control unit and the automatic switches and valves that sequence and time the different operations. SBR manufacturers should be consulted for recommendations on tanks and equipment. It is typical to use a complete SBR system recommended and supplied by a single SBR manufacturer.

The SBR tank is typically constructed with steel or concrete. For industrial applications, steel tanks coated for corrosion control are most common while concrete tanks are the most common for municipal treatment of domestic wastewater. For mixing and aeration, jet aeration systems are typical as they allow mixing either with or without aeration, but other aeration and mixing systems are also used. Positive displacement blowers are typically used for SBR design to handle wastewater level variations in the reactor.



*The decanter is the primary piece of equipment that distinguishes different SBR manufacturers. Types of decanters include floating and fixed. Floating decanters offer the advantage of maintaining the inlet orifice slightly below the water surface to minimize the removal of solids in the effluent removed during the DRAW step. Floating decanters also offer the operating flexibility to vary fill-and-draw volumes. Fixed decanters are built into the side of the basin and can be used if the Settle step is extended. Extending the Settle step minimizes the chance that solids in the wastewater will float over the fixed decanter. In some cases, fixed decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. Fixed decanters do not offer the operating flexibility of the floating decanters.*

### **Operation & Maintenance**

*The SBR typically eliminates the need for separate primary and secondary clarifiers in most municipal systems, which reduces operations and maintenance requirements. In addition, RAS pumps are not required. In conventional biological nutrient removal systems, anoxic basins, anoxic zone mixers, toxic basins, toxic basin aeration equipment, and internal MLSS nitrate-nitrogen recirculation pumps may be necessary. With the SBR, this can be accomplished in one reactor using aeration/mixing equipment, which will minimize operation and maintenance requirements otherwise be needed for clarifiers and pumps.*

*Since the heart of the SBR system is the controls, automatic valves, and automatic switches, these systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches.*

### **Performance**

*The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria. Depending on their mode of operation, SBRs can achieve good BOD and nutrient removal. For SBRs, the BOD removal efficiency is generally 85 to 95 percent. SBR will typically provide a process guarantee to produce an effluent of less than 10 mg/L BOD, 10 mg/L TSS, 5 - 8 mg/L TN and 1 - 2 mg/L TP.*

## Costs

*This section includes some general guidelines as well as some general cost estimates for planning purposes. It should be remembered that capital and construction cost estimates are site-specific. Budget level cost estimates presented in Table 11.3 are based on projects that occurred from 1995 to 1998. Budget level costs include such as the blowers, diffusers, electrically operated valves, mixers, sludge pumps, decanters, and the control panel.*

**Table 11.3 SBR EQUIPMENT COSTS**<sup>37</sup>

<i>Design Flowrate (MGD)</i>	<i>Budget Level Equipment Costs (\$)</i>
<b>0.012</b>	94,000
<b>0.015</b>	137,000
<b>1.0</b>	339,000
<b>1.4</b>	405,000
<b>1.46</b>	405,000
<b>2.0</b>	564,000
<b>4.25</b>	1,170,000

## Advantages

- *Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.*
- *Operating flexibility and control.*
- *Minimal footprint.*
- *Potential capital cost savings by eliminating clarifiers and other equipment.*

## Disadvantages

- *A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.*
- *Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves.*

- *Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.*
- *Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.*
- *Potential requirement for equalization after the SBR, depending on the downstream processes.*

### ***Comparison of Activated Sludge (AS) Process and Sequencing Batch Reactor (SBR)***

- *The treatment efficiency of the AS and SBR systems based on BOD removal is similar during the all cases of operation (the BOD removal ranged between 97.4 % and 98.1 % for both systems).*
- *The AS system has a higher ability to remove the suspended solids than the SBR system during all cases of operation (the TSS removal for AS and SBR systems 96.5 % and 93.6 % respectively).*
- *The SBR system has a higher ability to remove the total nitrogen TKN concentration than the AS system under all cases of operation (the TKN removal for SBR system ranged from 82.4 % to 88.2 %, and for AS system ranged from 77.1 % to 83.8 %).*
- *The SBR system has a higher ability to remove the total ammonia  $\text{NH}_3 +$  concentration than the AS system under all cases of operation (the  $\text{NH}_3 +$  removal for SBR system ranged from 96.3 % to 99.0 %, and for AS system ranged from 89.6 % to 90.4 %).<sup>38</sup>*

## References

1. GPCB Annual Report 2014-15, page No. 26
2. "Revised Guidelines for the Centrally Sponsored Scheme of Common Effluent Treatment Plants (CETPs)" by MoEFCC on 07/07/2015
3. <http://www.oilgae.com/algae/cult/sew/new/slu/slu.html>
4. A Novel Biological Approach for Treatment of Stripped-Sour Water ( A Biopetroclean article) February / March 2010
5. <http://www.oilgae.com/algae/cult/sew/new/slu/slu.html#sthash.h0mSepVY.dpuf>
6. Paper on BPC's ACT Biological Solutions for Refinery Wastewater, page No. 2,3.
7. Paper on "Introducing a Waste water treatment paradigm Shift" November 2014 by BPC biopetroclean.
8. Document on Harit industry (April - June, 2015, Volume 13, No. 02, ISSN No: 2454-4493)
9. <http://ecovillage.org.in/ecopedia/a-flush-story-iii-soil-biotechnology-plant-at-govardhan-eco-village>
10. Paper on soil biotechnology by Govardhan Eco Village 2/7/2013
11. Paper on "INNOVATIVE COD/BOD REDUCTION & EFFLUENT RECYCLING THROUGH SOIL BIOTECHNOLOGY (SBT) SYSTEM" by SUGAM PARYAVARAN VIKALP PVT LTD, MUMBAI, 28TH APRIL, 2015 – HYDERABAD
12. <http://www.lagoonsonline.com/reedbeds.htm>
13. <http://punenvis.nic.in/index3.aspx?sslid=244&subsublinkid=14&langid=1&mid=1>
14. <http://www.ciwem.org/policy-and-international/current-topics/water-management/reed-bed-wastewater-treatment.aspx>
15. Int. Journal of Engineering Research and Applications on Treatment of municipal and industrial wastewater by reed bed technology: A low cost treatment approach by Bansari M. Ribadiya\*, Mehali J. Mehta
16. <http://www.w2oenvironment.net/alternative.html>
17. [http://www.tpomag.com/online\\_exclusives/2013/03/reed\\_bed\\_technology\\_for\\_biosolids\\_dewatering\\_and\\_storage](http://www.tpomag.com/online_exclusives/2013/03/reed_bed_technology_for_biosolids_dewatering_and_storage)
18. "PESTICIDE WASTEWATER TREATMENT BY HYDRODYNAMIC CAVITATION PROCESS", International Journal of Advance Research in Engineering, Science & Technology(IJAREST), Volume 2, Issue 5, May- 2015, Impact Factor: 2.125 by Rajendrasinh R. Gaekwad and Prof. Reshma L. Patel.
19. Paper on "Aerobic Membrane Bioreactor for Wastewater Treatment – Performance Under Substrate-Limited Conditions" by Sebastián Delgado, Rafael Villarroel, Enrique González and Miriam, Morales Department of Chemical Engineering, Faculty of Chemistry, University of La Laguna, ( Page No.4)

20. *Paper on “Aerobic Membrane Bioreactor for Wastewater Treatment – Performance Under Substrate-Limited Conditions” (Page No.4) by Sebastián Delgado, Rafael Villarroel, Enrique González and Miriam, Morales Department of Chemical Engineering, Faculty of Chemistry, University of La Laguna*
21. *Metcalf & Eddy, page No. 1122 ,Table No. 11-20*
22. *Borkar R.P, Gulhane M.L, and Kotangale A.J “Moving Bed Biological Reactor – A New Perspective in Wastewater Treatment” IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402,p- ISSN: 2319-2399. Volume 6, Issue 6 (Nov. - Dec. 2013), PP 15-21*
23. *<http://tpacific.com/pdf/moving-bed-bio-reactor.pdf>*
24. *Paper on Wet Air Oxidation Of Waste Water Sludge by Paul M. Rose, Kevin J. McKay, Stephen J. Tallon, Owen J. Catchpole and Thomas Mollenhauer*
25. *<http://www.energy.siemens.com/mx/en/industries-utilities/oil-gas/portfolio/water-solutions/zimpro.htm>*
26. *<http://water-research.net/index.php/ozonation>*
27. *<http://www.faradayinstruments.com/applications/waste-water-treatment>*
28. *Paper on “Visit Report Of Effluent Treatment Plants/ Common Effluent Treatment Plants” by VijaiSinghal and K.C Gupta, Rajasthan State Pollution Control Board, Jaipur*
29. *AlenaTetreault EC Pacific Pty Ltd Level 4/352 Kent St Sydney NSW 2000 February 2003 “Electrocoagulation Process for Wastewater Treatment” Page No. 8*
30. *e-ISSN 2277-2685, p-ISSN 2320-976 IJESR/August 2014/ Vol-4/Issue-8/584-589 Shreesadh EC et. al./ International Journal of Engineering & Science Research*
31. *TREATMENT OF INDUSTRIAL WASTEWATER BY FENTON PROCESS COMBINE WITH COAGULATION by Faculty of Chemical and Natural Resources Engineering University Malaysia Pahang*
32. *<http://www.h2o2.com/industrial/fentons-reagent.aspx?pid=143&name=General-Chemistry-of-Fenton-s-Reagent>*
33. *“Water and Wastewater in India” by European Business and Technology Centre, Page No. 6*
34. *SEQUENCING BATCH REACTOR DESIGN AND OPERATIONAL CONSIDERATIONS by NEW ENGLAND INTERSTATE WATER POLLUTION CONTROL COMMISSION September 2005*
35. *Paper on Sequencing Batch Reactor in wastewater treatment by Susheel Arora, M.A.Sc, P.Eng.*
36. *Wastewater Technology Fact Sheet Sequencing Batch Reactors by United States Environmental Protection Agency EPA 832-F-99-073 September 1999*
37. *Wastewater Technology Fact Sheet Sequencing Batch Reactors by United States Environmental Protection Agency EPA 832-F-99-073 September 1999*

38. *Amr M. Abdel\_Kader* “COMPARISON STUDY BETWEEN SEQUENCING BATCH REACTOR AND CONVENTIONAL ACTIVATED SLUDGE BY USING SIMULATION MATHEMATICAL MODEL”  
*Thirteenth International Water Technology Conference, IWTC 13 2009, Hurghada, Egypt*





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