TECHNOLOGY SELECTION CRITERIA FOR WASTEWATER TREATMENT

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities*****.**

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **TECHNOLOGY SELECTION CRITERIA FOR WASTEWATER TREATMENT** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

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CHAIRMAN
PWON, Pakistan

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1. TREATMENT TECHNOLOGIES MOSTLY DISCUSSED IN PAKISTAN

- Waste Stabilization Ponds(WSP)
- Aerated Lagoons
- Conventional activated sludge process
- Trickling filters
- Up flow anaerobic sludge blanket(UASB)

2.THE QUALITY STANDARDS TO BE MET

Parameter	Standard (mg/l)
PH	06-09
TSS	200
TDS	3500
COD	150
BOD5	80
Oil & Grease	10
phenol	0.1
Cadmium (Cd)	0.1
Chromium (Cr)	1
Copper	1
Iron	8
Mercury	0.01
Chlorides	1000
Fluoride	10
Led	0.5
Amonia	40
Manganese	1.5
Sulphate	600
CN	1
Zn	5
Arsenic	1
Nickel	1
Chlorine	1

3. MAIN TECHNOLOGIES

3.1 WASTE STABILIZATION PONDS

- WSP are large shallow basins enclosed by earth embankments.
- Entirely natural processes involving both algae and bacteria.

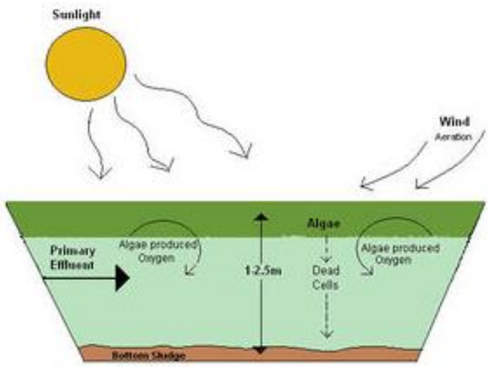
- Since these processes are unaided by wastewater treatment engineers the rate of oxidation is slower, and as a result hydraulic retention times are longer.
- Three types: Anaerobic ponds, Facultative ponds and Maturation ponds
- Anaerobic and facultative ponds are designed for BOD removal,
- while maturation ponds are designed for pathogen removal.

3.1.1 Anaerobic pond (No oxygen involved)

- They are 2–5 m deep and receive such a high organic loading (usually >100 g BOD/m3 day, for a depth of 3 m). Depends upon temperature.
- they contain no dissolved oxygen and no algae, They function much like open septic tanks, and their primary function is BOD
- BOD_5 removal is achieved by sedimentation of solids, and subsequent anaerobic digestion of the resulting sludge.
- A short retention time (1.0 day) is commonly used.
- The overall process can be described by the chemical reaction,
- where organic material such as glucose is biochemically digested into carbon dioxide (CO_2) and methane (CH_4) by the anaerobic microorganisms.
- $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$

3.1.2 Facultative ponds

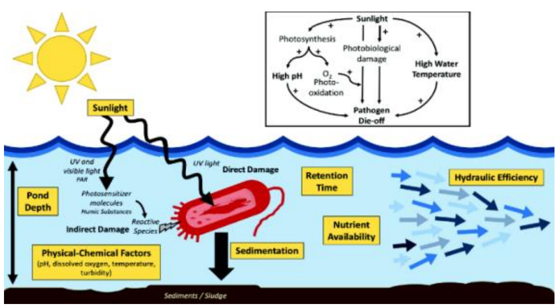
- They receive wastewater from anaerobic pond and depths are usually in the range 1–1.8 m, with 1.5 m being the most commonly used.
- They remove BOD on the basis of relatively low surface loading to permit the growth of algae.
- Anaerobic zone (in the bottom layer of the pond) and aerobic zone (in the upper layer) co-exist.
- Part of the organic matter in suspension (particulate BOD) tends to settle, constituting the bottom sludge. This sludge undergoes a decomposition process by anaerobic microorganisms and is converted into carbon dioxide, methane and other compounds.



- The dissolved organic matter does not settle and stays dispersed in the liquid mass. Aerobic respiration near the surface is carried out by facultative bacteria that have the capacity to survive, either in the presence or in the absence of free oxygen (but presence of nitrate).
- Oxygen is supplied to the medium by the photosynthesis carried out by the algae. The retention time is between 15 to 20 days

3.1.3 Maturation Ponds

- Most bacterial pathogens are vulnerable to high pH.
- At peak algae activity, the pH of water can rise to above 9, leading to Fecal Coliform (FC) inactivation and promoting ammonia volatilization(ammonia gas).



3.1.3.1 Governing factors in designing of WSP.

Mean temperature of the coldest month and BOD load

Anaerobic Pond

Temperature (°C)	Volumetric loading (g/m^3)
10	**100**
10-20	**20T-100**
20-25	**10T+100**

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If coldest month is January with mean temperature 14°C

BOD_5 loading will be 20×14-100=180 g/m3 as per above table and if mean temperature is 12 it will become 140g/m3

Facultative ponds

- Surface organic loading rate (Ls)=$350(1.107 - 0.002T)^{T-25}$
- If mean temperature in the coldest month is 14 the value of Ls becomes 151.65 kgBOD_5/ha.d
- Assume flow is 100,000m3/day and BOD of influent entering facultative pond is 200g/m3
- Total BOD_5 load of influent is=200×100,000/1000 = 20,000 kgBOD_5/ d
- Land required =20000 /151.65= 131.88 ha = acres =1318826.24 m2
- If depth is 1.5m the volume will be=1978,239m3
- Detention time=volume/flow=1978,239/100,000=19.78 or 20 days.

Effluent soluble BOD_5

- K_t=BOD removal coefficient at a temperature T/day
- $K_t = K_{20}.\ \theta^{(T-20)} = K_t = 0.32*1.05^{(14-20)}$
- =0.238/day
- Where θ is the Arrhenius constant, whose value is usually between 1.05 - 1.09
- Range of K=0.25-0.32/day at 20^{0}C
- K_t=BOD removal coefficient at a temperature T/day
- Effluent BOD(S)=S_o/1+K_{t*}T=200/1+0.238 ×20=34.7mg/l

- If mean air temperature is 25 then K_t=0.32*1.05$^{(25-20)}$=0.408
- Effluent BOD(S)=200/1+0.408*15(detention time will be less in summer)=28mg/l

What affects lagoon pH?

- Algal activity is responsible for most of the variation in the lagoon. Algae consume CO2 as part of the photosynthesis process, driving up pH.
- pH is highest in the late afternoon—up to about 7.6—when algae is most active, and lowest just before dawn—at around 6.8—as photosynthesis stops overnight. And because algae thrive in the surface layers of the lagoon, pH tends to be higher near the surface and drop as you get deeper.

How to Adjust Wastewater Lagoon pH

- Very high or low pH is often the result of industrial influent, such as acidic dairy wastewater or alkaline cleaning chemicals, or even naturally hard or soft local water, so it's important for the operator to know what's coming it and make pH adjustments as necessary to the influent before it enters the lagoon.This does not happen frequently.
- A low or decreasing pH is often caused by low dissolved oxygen (DO) or organic overloading.
- A pH below 6.5 (acidic conditions) generates excessive odor and sludge production.To increase pH, add lime and mix it throughout the lagoon.

TDS for brackish water is up to 10,000

- Electrical conductivity, can be monitored to observe lagoon performance.
- An electrical conductivity range of 2,000 to 8,000 µmho/cm (micro mohs per centimeter) indicates acceptable levels of salt concentration for WSP.
- A level greater than 10,000 µmho/cm can indicate high salt concentrations in the effluent that will inhibit plant growth.
- Factors that mainly govern the performance of WSPs are sunlight, algae, microorganisms, and oxygen.

3.1.3.2 Advantages and Disadvantages of WSP

ADVANTAGES	DISADVANTAGES

Reduced construction and operation cost	High land requirement
No mechanical equipment required therefore no energy requirement	Difficulty in satisfying restrictive discharge standards
Satisfactory BOD removal efficiency	Variable performance with climatic conditions
Simple construction operation and maintenance	Possible insect growth
Satisfactory resistance to load variations	Possible need for removing algae from effluent to comply with stringent discharge standards

3.2 AERATED LAGOONS

- It is similar to a facultative pond but mechanical aerators are used.
- Detention time is 5-10 days
- Usually 2.5-4 meters deep
- The aerators more frequently used for aerated lagoons are the mechanical vertical-shaft high-speed floating aerators.
- The sludge accumulation rate is in the order of 0.03 to 0.08 m3/inhab.year
- Requires frequent desludging

Advantages & Disadvantages of AL

Advantages

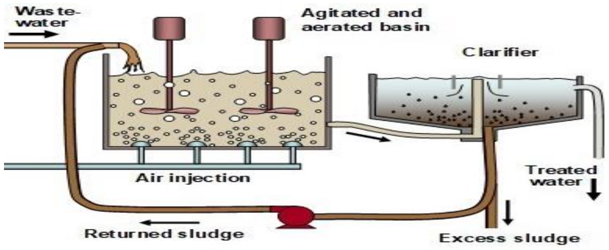
- Lower land requirements than WSP
- Greater independence from climatic conditions than the facultative and anaerobic-facultative pond systems.
- Satisfactory resistance to load variations
- Reduced possibilities of bad odours

Disadvantages:

- Introduction of equipment
- Slight increase in the sophistication level
- Land requirements still high
- Relatively high energy requirements
- Low coliform removal efficiency
- Need for periodic (some years interval) removal of sludge from aerated pond

3.3 Conventional activated sludge process

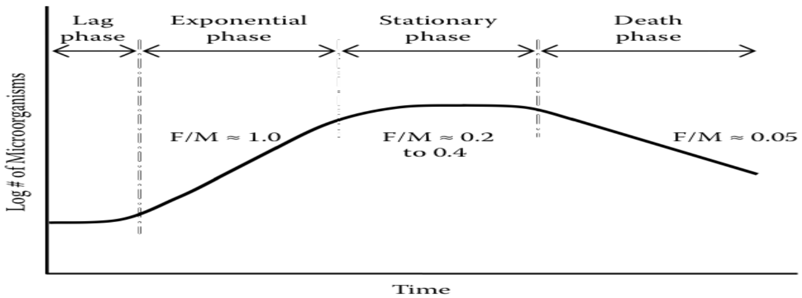
Control Factors



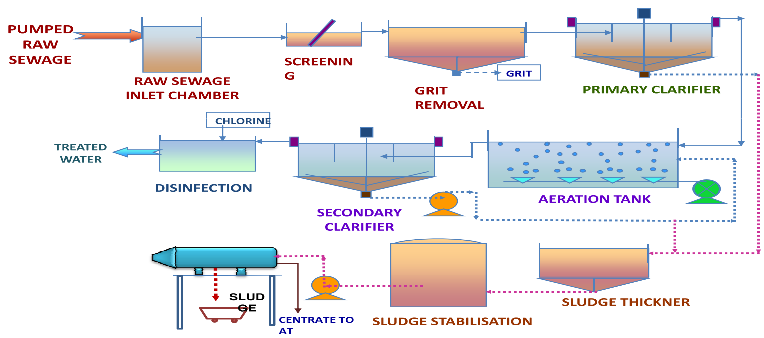
- **SRT/MCRT**(Mean Cell Residence Time or solids retention time): Fundamental parameter. It is also called sludge age.
- The average time suspended solids remain in the activated sludge system. Typical sludge age are: $\theta c = 5$ to 10 days

Food to microorganisms ratio (F/M)

- F/M ratio is an important design variable that dictates the phase of operation on the microbial growth curve.



- A low F/M ratio of about 0 .0 5 indicates operation in the decay phase, while a high F/M ratio around 1.0 and above indicates log growth phase.
- F/M ratio for CAS= 0.25–0.5
- By maintaining this ratio through return activated sludge bacteria will consume high percentage of the food
- **Hydraulic retention time(HRT).**
- It is the time spent by a fluid particle in the reactor, before it is discharged to secondary clarifier. Typical 6-8 hours
- MLSS—mixed liquor suspended solids. The concentration of suspended solids, in an aeration tank. It consists both microorganisms and non-biodegradeable matter.
- The portion of the MLSS that is actually eating the incoming food is referred to as (MLVSS).
- The volatile solids concentration is approximately equal to the amount of microorganisms.
- MLVSS should be between 70 and 80 percent of the MLSS.
- For carbonaceous removal pH in the range of 6 to 9 is tolerable

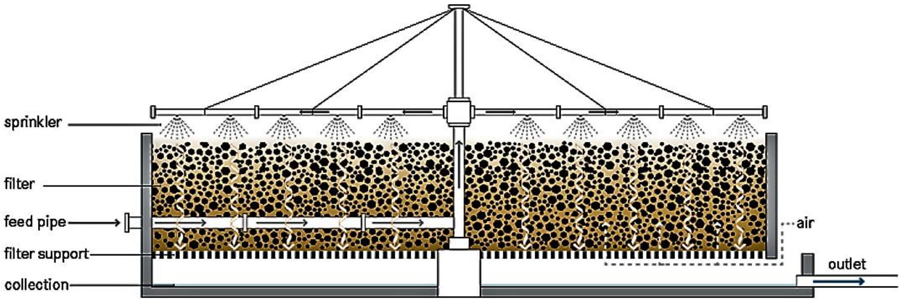


Advantages and Disadvantages of conventional activated sludge process

ADVANTAGES	DISADVANTAGES
Low land requirements	High construction and operation costs
High BOD removal efficiency	High energy consumption, due to sophisticated operation required

Biological removal of N and P is possible	Requires complete treatment and final disposal of the sludge
Reliable process, as long as it is supervised	Low coliform removal efficiency

3.4 TRICKLING FILTERS



- An attached growth process. The influent wastewater is distributed/sprinkled over the rock or plastic filter and then trickles down the packing material,
- microorganisms already in the water gradually attach themselves to the media surface and form a biofilm(approximately 0.1 to 0.2 mm thick).
- The sewage is oxidized by the bacteria producing effluent in the form of water, gases and new cells.

Principal features of TF

- The filter media (75 to 100 mm rock material or plastic packing),
- wastewater distribution system and,
- the underdrain system, which collects the wastewater that has passed through the filter and provide an open area for the movement of air.
- Hydraulically driven rotary distributors use pneumatically-controlled gates that either open or close distributor orifices that adjust with varying pumped flows to maintain a constant preset rotational speed (left). Electrically driven rotary distributors are also used.

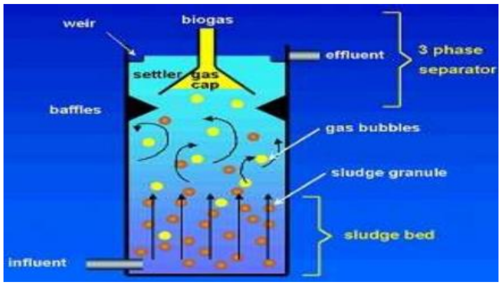
Categories of TF

Design parameter	Low rate	Intermediate rate	High rate
Type of packing	Rock	Rock	Plastic
Hydraulic loading m3/m2-d	1-4	4-10	10-75
Depth	1.8-2.4	1.8-2.4	0.6-3.2
BOD removal efficiency	80-90	50-80	60-90
Effluent quality	Well nitrified	Some nitrified	No nitrification
Power KW/10^3m3	2-4	2-8	6-10

Advantages and Disadvantages of Trickling Filters

Advantages	Disadvantages
Simple & easy to operate as compared to activated sludge	Difficulty in accomplishing biological nitrogen & phosphorus removal
Less energy required due to natural ventilation	Flies, worms and snails& odor can be nuisance
Appropriate for small- to medium-sized communities.	Additional treatment may be needed to meet more stringent discharge standards.
Less O&M	Clogging if overloaded
Possible energy production from sludge digestion	Not as efficient as CAS

3.5 Upflow anaerobic sludge blanket reactor.



- The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants It covers 30 to 60% of the total reactor volume

- The blanket begins to reach maturity at around three months.
- Wastewater flows upwards through the blanket and is processed (degraded) by the anaerobic microorganisms.
- Organic components (COD) are converted to $CH_4 + CO_2$ + biomass
- Generally, COD concentration greater than 1500 to 2000 mg/L are needed to produce sufficient quantities of methane to heat the wastewater without an external fuel source.
- If you focus only on COD removal, low concentration even < 100 mg/L would be OK.

Advantages and Disadvantages UASB

Advantages	Disadvantages
Requires smaller reactor volume	Needs post treatment as pathogens and nutrients are not removed completely.
Simple construction and low O&M. Needs low energy requirement	Long startup time is required due to the slow growth rate of microorganisms
Robustness in treatment efficiency and wide applicability from very small to very large scale	H_2S is generated particularly when there is high concentration of sulfate in the wastewater.
Energy is generated as methane gas.	A proper temperature range is required for the anaerobic process (15 C to 35 C), therefore it is not applicable during cold season in certain countries.
Low sludge production as compared to aerobic processes.	The biogas needs further suitable handling to avoid bad odor.

4. SELECTION CRITERIA

4.1 Professor Ahmed Saatsi President SUEN(Turkish water Institute)

- Technology selection depends on Management Questions:
  Which pollutants should be removed?
- Carbon Only, (C)
- C and TKN oxidation (nitrification) (C, N)
- Carbon, Nitrification & Denitrification (C, N, D)
- Carbon, Nitrification, Denitrification, Biological & Chemical P Removal (C, N, DN, P)

Process Selection

- Simple, Robust
- Modular (Expandable)
- Minimum Elecro-mechanical equipment (especially under water)
- Not to Construct Over or Under Capacity

4.2 Richard Helmer and Ivanildo Hespanhol:

"A Guide to the Use of Water Quality Management. The United Nations Environment Programme, The Water Supply & Sanitation Collaborative Council and The World Health Organization"

4.2.1 The best available technology not entailing excessive costs

- Average, or typical, efficiency and performance of the technology
- Reliability of the technology. The process should, preferably, be stable and resilient against shock loading.
- Produce an acceptable effluent under unusual conditions. Flow variations etc.
- Institutional manageability. Appropriate technical and managerial expertise must be present. Extensive education and training.
- Financial sustainability. The lower the financial costs, the more attractive the technology.

- In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses.
- Application in reuse schemes. Resource recovery. It can include agricultural irrigation, aqua-and industrial cooling and process water reuse, or low-quality applications such as toilet flushing. The use of generated sludge can only be considered as crop fertilizer.

4.2.2 Operation and maintenance cost

- Recurring costs
- Paying back of loans (interest and principal)
- Costs for personnel,
- Energy and other utilities,
- Stores, laboratories, repair and sludge disposal.

4.2.3 Classification of secondary treatment technology

Treatment method	Mechanized technology	Non-mechanized technology
Aerobic	Activated sludge	Waste stabilization ponds. Facultative
	Trickling filter	Maturation ponds
Anaerobic	Up flow anaerobic sludge blanket (UASB)	Anaerobic ponds

4.2.4 The choice between aerobic and anaerobic technology

- The supply of large amounts of oxygen by aeration system adds to the capital cost of the aeration equipment substantially, as well as to the running cost because the annual energy consumption is rather high (it can reach 30 kWh per population equivalent (pe).

Criteria	Aerobic process	Anaerobic process
BOD removal	90-95%	75-85%

Post treatment	Not required	Normally post treatment required to achieve quality standards
N and P removal	Better removal	Minimal
Sludge	Large quantity	Less than 50% of aerobic process and better stabilized
Biogas recovery	No	Large scale plants or industry

4.2.5 Non-mechanized technologies

- Non-mechanized technologies rely on substantially longer retention time to achieve a high degree of contaminant removal therefore, need large land.
- If land costs are equal or in excess of USD 20 per square meter, non-mechanized systems(WSP) lose their competitive cost advantage over mechanized systems.
- Stabilization ponds may be feasible only when flat land costs are below US$ 5 per square meter.

4.2.6 Mechanized treatment: UASB

- If the average sewage temperature is above 20 °C (with a minimum of 18 °C over a maximum period of 2 months) and, is highly biodegradable (COD: BOD ratio below 2.5),anaerobic(UASB) treatment has clear economic advantages.
- When high effluent standards are to be met, and the cost of land is moderate to high, the combination of a UASB plant plus aerobic post-treatment is often decisively more cost-effective than conventional aerobic treatment.
- Reliability of power supply: aerobic treatment performance is highly dependent on power input for aeration and mixing. Power failure may create rapid malfunctioning of aerobic plants while anaerobic systems are fairly resistant to periods of no power supply.

4.2.7 Activated sludge system

- If flat land is scarce or expensive, and if anaerobic technologies are not feasible, the remaining option is to use conventional, aerobic, mechanized technologies.

- Most wastewater treatment plants all over the world are presently of this type, although they tend to be less appropriate in low-cost environments.
- The activated sludge system, in its various designs, is the most widely applied - offering operational flexibility, high reliability and resilience.
- An added advantage is that process control also offers the opportunity to have several processes integrated in the system such as carbon oxidation, nitrification, Denitrification and biological P-removal.

4.2.8 Trickling filters

- Technically feasible and attractive because they are easy to operate and they consume less energy,
- they generally have a lower removal efficiency for BOD and TSS,
- they are sensitive to low temperatures and, may be infested with flies and mosquitoes.
- Their N and P removal is too low to justify wide application in countries with stringent effluent quality standards

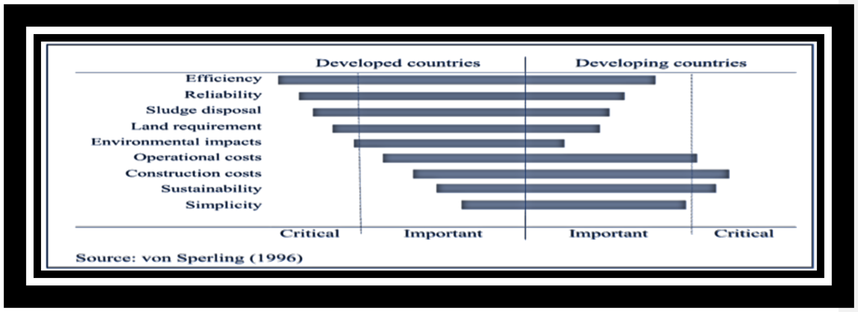
4.2.9 Comparative analysis of the performance of the trickling filter and the activated sludge process

Parameter	Trickling filter	Activated sludge
BOD removal (%)1	80-90	90-98
Kjeldahl-N removal (%)	60-85	80-95
Total N removal (%)	20-45	65-90
Energy required (kWh cap-1 d-1)	10-15	20-30
O&M requirement	Medium	High
Pathogen removal	1-2 orders of magnitude	1-2 orders of magnitude

4.3 Marcos Von Sperling

"Professor of Sanitary and Environmental Engineering "Biological Wastewater Treatment in Warm Climate Regions" 2005

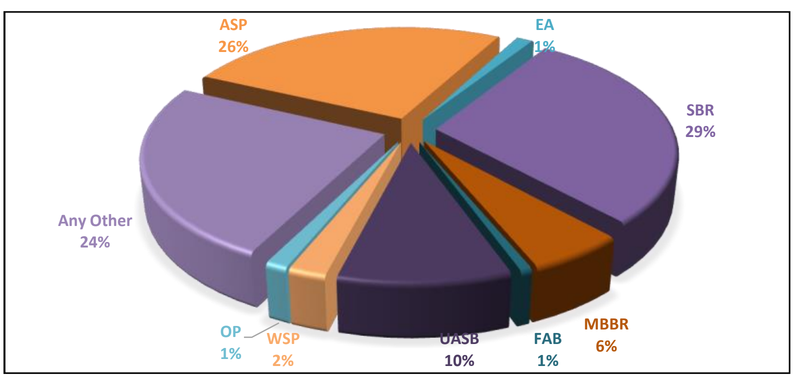
4.3.1 Critical comparison



Developed countries	**Developing countries**
Efficiency,	**Construction Costs**
Reliability,	**Sustainability**
Sludge disposal	**O&M cost**
Land requirement	**Simplicity**
Environmental impacts	Efficiency
Simplicity	Reliability
Operation cost	Sludge disposal

4.4 Treatment technologies used in Indian states having similar climate like Pakistan

Technology wise Capacity Distribution of STPs in India.



Total Capacity of Activated sludge plus its variants is=63%

Total Capacity of WSP plus oxidation ponds is=3%

4951 MGD with 783 As and its variants

257.6 MGD with 97 WSP or OP

Source: Central pollution Control Board 2021

4.4.1 Treatment technologies in 04 Indian states having similar climate like Pakistan

	Activated sludge plus its variants			Oxidation ponds/WSP	UASB	ANY OTHER
STATE	ASP 1	EA, SBR, MBBR, FAB 2	Combined capacity(1+2)	WSP/OP	UASB	Aerated lagoon, TF, MBR, etc.
	Number	Number	Number	Number	Number	Numbe
	MGD	MGD	MGD	MGD	MGD	MGD
Punjab	4	67	71	16	7	1
	45	185	230	11.5	110	0.7
Rajasthan	13	24	37	11	9	5
	88	35	123	26	20	18
Utter Pradesh	19	37	56	13	24	6
	135	287	422	23	240	24
National Capital Region (9 distt.) Delhi	**25, 526**	**9, 70**	**34, 596**	0	0	1
Total Number	**67**	**137**	**204**	**40**	**40**	**13**
Total Qty MGD	**794**	**577**	**1371 MGD**	**60.5 MGD**	**370**	**40**

4.4.2 Maximum Capacity Of WSP in Nearing Indian States Having Similar Climate Like Pakistan

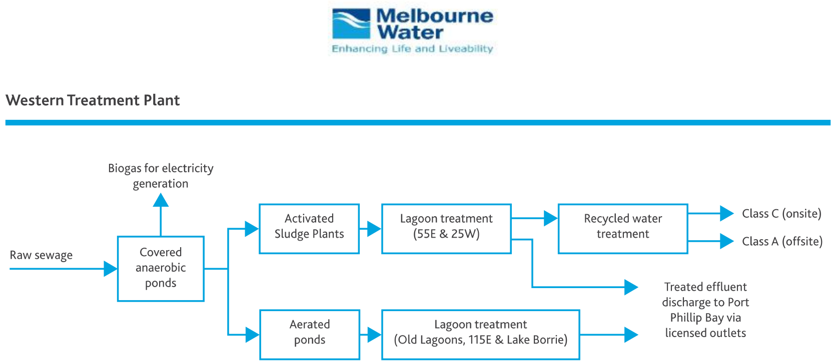
- Punjab: WSP capacity ranges from 1000 to 14000 m3/day (3MGD) (total 16 plants)
- Rajasthan: biggest WSP is of 24000m3/d (5.3MGD) (total11plants)
- UP: Biggest WSP is of 18000m3/day (4MGD)(total 13 plants)
- So overall no WSP is bigger than 24000m3/d (5.3MGD) capacity

4.4.3 Waste Stabilization Ponds around the world

- About one third wastewater treatment plants in the world are Waste stabilization ponds usually serving populations up to 5000 (less than 5000m3/day) (about 1 MGD).
- However in warmer climates (the Middle East, Africa, Asia and Latin America) ponds are commonly used for large populations(up to around 1 million).
- There is no example of larger plants like 500,000m3/(110MGD)day or more.

4.4.4 Once the biggest WSP, Werribee treatment complex Melbourne, Australia

- The first treatment lagoon was constructed in 1936. Its capacity is 107 MGD for 1.5 million populations.
- Originally Three treatment systems: land filtration, grass filtration and stabilization ponds were constructed.
- Lagoon treatment facilities have been continuously upgraded to meet the needs of Melbourne's growing population.
- Today, Activated sludge and aerated lagoon system added before the old facultative lagoons which are used only for polishing now. Now there is no pure WSP system here. Only blending of AS and AL with ponds exist.



Current Flow process:

- Anaerobic ponds (covered to tap methane gas)
- All flow divided into 2 parts:
- 1st part goes to activated sludge process for 71 MGD
- 2nd part to aerated lagoon 35MGD
- After both type of aerobic treatment both flows go to facultative ponds.

Melbourne treatment plant

4.4.5 Current status of once largest WSP Plants

Name	Flow MGD	Remarks
Werribee, Melbourne	110 total	It is not WSP alone. A blend of activated sludge, aerated lagoon and Ponds
Manukau, Auckland (Mangere)	66	Decommissioned in 2002 due to inability to reduce nitrogen to ≤5 mg
Dandora, Nairobi	26	In operation

Al Samra, Amman	33	Due to overloading and stringent effluent parameters Now converted into AS

4.4.6 Now the largest WSP Plants in the world

Name	**Flow MGD**	**Remarks**
Dandora, Nairobi	26	In operation Effluent standards problem
Faisalabad	20	In operation

4.5. Average effluent quality of various technologies

TREATMENT SYSTEM	**Average effluent quality**				
	BOD	COD	SS	Total N	Total P
Conventional activated sludge	15-40	45-120	20-40	> 20	>4
High rate TF	30-60	80-180	20-40	> 20	>4
Aerated Lagoons	50-80	120-200	60-90	> 30	>4
Waste Stabilization Ponds	50-80	120-200	60-90	> 20	>4

4.6 Wichitra Singhirunnusorn, University Of California

"A Critical Analysis Of Economic Factors For Diverse Wastewater Treatment Processes: Case Studies In Thailand

Cost Comparison at various flows

The publication "*A critical analysis of economic factors for diverse wastewater treatment processes: case studies in Thailand*" (Singhirunnusorn & Stenstrom, 2010) is applied for comparing capital costs and O&M costs (*incl.* equipment replacement and power recovery for sludge digestion) for a range of treatment processes commonly utilized in the region. This includes activated sludge, oxidation ditches, waste stabilization ponds and aerated lagoons. For capital costs, the expected values for trickling filters lie in the cost range between aerated lagoons and oxidation ditches. For O&M costs, trickling filters are similar to aerated lagoon.

4.6.1 Formulas for comparison of options.

Process	Capital Costs	O&M Costs
	(US million)	**(US million/year)**
Activated Sludge	$C_c = 0.0031 \times Q^{0.881}$	$C_{O\&M} = 0.0529 + 1.31 \times 10^{-5} F$
Oxidation Ditches	$C_c = 0.0017 \times Q^{0.910}$	$C_{O\&M} = 0.0963 + 1.02 \times 10^{-5} F$
Aerated Lagoons	$C_c = 0.0143 \times Q^{0.681}$	$C_{O\&M} = 0.0607 + 3.31 \times 10^{-6} F$
Waste Stabilisation Ponds	$C_c = 0.0004 \times Q^{1.060}$	$C_{O\&M} = 0.018 + 4.03 \times 10^{-6} F$

Note: Q is the design flowrate (m^3/day); F is the actual flowrate (m^3/day).

In order to compare the options on total life-cycle costs. Assuming a discount interest rate of 5.0%/annum and a 20 years design horizon, the capitalization factor is 12.46.

Technology	Capital cost in million USD	Capitalized O&M in million USD	Life cycle cost in million USD
Capacity: 100,000m3/d			
Activated sludge	78.77	16.98	95.75
Trickling filter	47.26	4.92	52.19
Oxidation ditches	60.32	13.91	74.23
Aerated Lagoons	36.34	4.88	41.22
Waste Stabilization Ponds	79.81	5.25	85.06

Capacity: 200,000m3/d			
Activated sludge	145.07	33.30	178.37
Trickling filter	85.59	9.33	94.91
Oxidation ditches	113.34	26.62	139.96
Aerated Lagoons	58.26	9.00	67.26
Waste Stabilization Ponds	166.40	10.27	176.67

Capacity: 400,000m3/d			
Activated sludge	267.16	65.95	**333.11**

Trickling filter	154.95	17.81	172.76
Oxidation ditches	212.97	52.04	265.01
Aerated Lagoons	93.40	17.25	110.65
Waste Stabilization Ponds	346.93	20.31	**367.24**

4.7 Comparison of Land Requirement (Based on literature)

Technology	**FLOW**		
	20MGD/day	50MGD/day	100MGD/day
	Acres	Acres	Acres
Activated sludge	45	113	227
Trickling filter	45	113	227
Aerated Lagoons	125	313	600
Waste Stabilization Ponds	270	675	1350

4.8 RECOMMENDATIONS BY JICA STUDIES

Comparison as per JICA study of Ganga River India 2005 Lucknow City with flow of 100,000m3/day

Technology	**Capital cost**	**O&M**	**Capitalized cost**	**Land in hectares**	**Land cost applied**
WSP	15.24	0.138	17.36	101.21	USD 5/m2
AS	10.35	0.91	21.63	20.24	
AL with maturation ponds	9.51	0.74	20.83	55.87	

So if land cost is USD20/m3 then the cost of WSP becomes higher than AS but if Land cost is USD 5/m2 the WSP is cheaper than AS and Aerated Lagoon.

4.8.1 Recommendation of JICA study of WASA Lahore 2010

Item	**Aerated Lagoon**	**Trickling filter**	**Stabilization ponds**

Energy demand Electricity cost	Poor	Fair	Good
Simple operation	Fair	Fair	Good
Land requirement	Good	Good	Poor
Overall judgment		✡	

WSP was dropped due to more land requirement than already acquired by WASA (7300Kanal)

Recommendations: Anaerobic ponds+ Trickling filters

4.8.2 WHY DID JICA RECOMMEND TF

- *"With regard to the stabilization pond, if additionally land acquisition is available, then the total area will be more than 20,000 kanal approximately.*
- *It is an unrealistic area for operations because stabilization ponds also require sludge removal periodically. In many instances, stabilization ponds operated without proper maintenance do not unfortunately function properly".*
- *"Meanwhile as mentioned above, aerated lagoons have high energy demands. Its energy demand would be a problem given both the current financal condition of WASA and the power supply conditions in Pakistan. Improvement of these conditions are not expected in the short term".*
- *"Therefore, considering these reasons, the Trickling Filter method is recommended".*

4.8.3 Faisalabad Master Plan

- Option 1: Anaerobic pond + Facultative pond (Stabilization pond) Although the required land area is the largest ,regular maintenance of ponds is not required except periodical sludge removal from the anaerobic ponds (once every 3 to 5 years).
- Option 2: UASB + Facultative pond The required area is about 65% compared with that of Option 1. This is advantage when Option 1 is difficult to apply.

- Option 3: Anaerobic pond + Trickling filter The required land can be reduced to only about 10% of that required for Option 1. This is the best option when the site area availability is very severe case.
- Note: Above recommendations were made considering existing WSP ponds system and available land for extension of capacity

4.9 Chances of Energy Recovery

- Energy recovery is possible from AS and TF therefore, while evaluating the technologies this aspect may also be considered.
- DANIDA study 2017 for Faisalabad wastewater treatment plant proposed 40% energy recovery from Trickling Filter system.
- In the USA, wastewater treatment CHP systems are present in 133 sites and, as of June 2011, represent 437 MW of capacity.
- There are currently no high-energy self-sufficient (>90%) WWTPs in developing countries, where a large gap for energy self-sufficient WWTPs still exists.

5. POSSIBLE CONCLUSION

- As the Aerated lagoon also needs considerable land and it also has other problems like not efficient in removing suspended solids concentrations and faecal bacteria (Mara, 2004). High algae content in effluent that could be problematic for surface discharge is also commonly observed in aerated lagoons (Arceivala, 1981) therefore;
- where land is available in abundance and cheap about USD 5/m2, WSP technology may be the most feasible technology especially when the flow is less than 40 MGD.
- In urban areas where the land is very costly there are two options:
- Trickling filter technology being easy to operate and consume less energy may be feasible however odor and snail problem will be faced.
- If some Utility can arrange O&M and wants to avoid the snails, worms, flies and odor problem and wants to get a very good & clear effluent with more BOD removal, Conventional activated sludge system may be the ultimate choice.

6. SLUDGE HANDLING AND ENERGY GENERATION FROM ITS BIOGAS

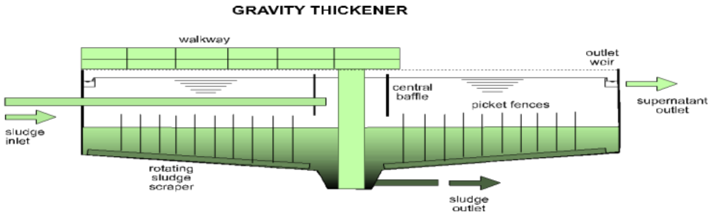
- Sludge collection

SLUDGE THICKENING

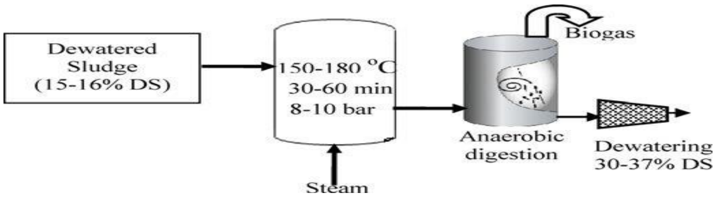
- The main processes used for sludge thickening are:
- gravity thickeners
- dissolved air flotation
- centrifuges
- belt presses

6.1 Gravity thickeners

- Gravity thickeners have a similar structure to settling tanks. The format is usually circular with central feeding, a bottom sludge exit and a supernatant side exit. The thickened sludge goes on to the next stage (normally digestion), while the supernatant is returned to the head of the works.
- Dry solids levels in thickened sludges, according to process4-8%



6.2 Hydrolysis



- In order to maximize the biogas production in the anaerobic digesters, hydrolysis is considered.

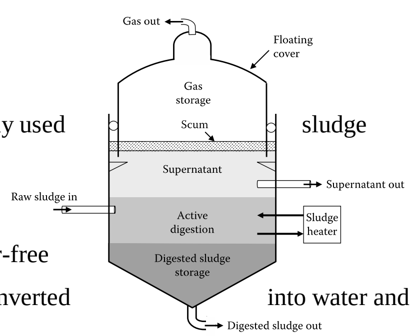
- The process is driven with a temperature of at least 70 ºC and with the pressure level of 30-60 megabar. The retention time is designed so that there is no biogas production in the tanks. This condition also insures hygienisation of sludge.
- Hydrolysis is normally expected to increase the amount of produced biogas in the digesters by 10-20%.

6.3 SLUDGE STABILISATION

- Raw sewage sludge is rich in microorganisms, decomposes easily and quickly releases offensive odors.
- The stabilization processes were developed with the objective of stabilizing (digesting) the biodegradable fraction of the organic matter present in the sludge, thus decreasing the risk of putrefaction, as well as reducing the concentration of pathogens.
- The stabilization processes can be divided into :
- biological stabilization: use of specific bacteria to promote the stabilization of the biodegradable fraction of the organic matter
- chemical stabilization: the stabilization is achieved by the chemical oxidation of the organic matter
- thermal stabilization: obtained from the action of heat on the volatile fraction in hermetically closed recipients.

6.4 Anaerobic Digester

Biological stabilization



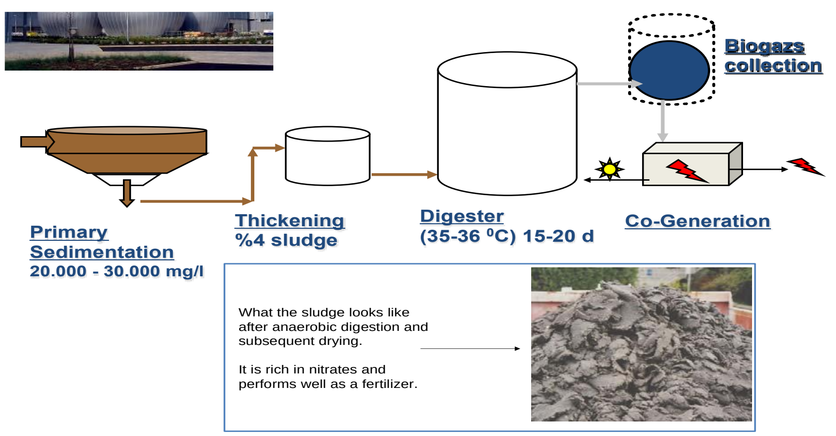
- Anaerobic digestion is the most frequently used sludge stabilization process.
- In roughly 20 days, the sludge is subjected to controlled digestion in an air-free atmosphere and the organic content is converted into water and biogas.

- The digester gas (biogas) thus released, which consists of a mixture of 50-70% methane, 30-40% CO_2, 0-1% steam and trace elements.
- During this process the mass and volume of volatile solids is reduced
- The raw sludge is mixed – and heated in temperate climate countries with heat exchanger utilizing heat from cogeneration

6.5 Combined heat and power (CHP)

- CHP is an energy efficient technology that generates electricity and captures the heat that would otherwise be wasted to provide useful thermal energy—such as steam.
- CHP is typically located at facilities where there is a need for both electricity and thermal energy.
- CHP can achieve efficiencies of over 80 percent, compared to 50 percent for typical technologies (i.e., conventional electricity generation and an on-site boiler).

Cogeneration System (combined heat and power (CHP)



6.6 SLUDGE DEWATERING

The main reasons for sludge dewatering are:

- reduction of the transportation costs to the final disposal site

- improvement of the handling conditions of the sludge, since dewatered
- reduction in the volume for disposal in a landfill or for agricultural use;
- The main sludge dewatering processes are listed below:

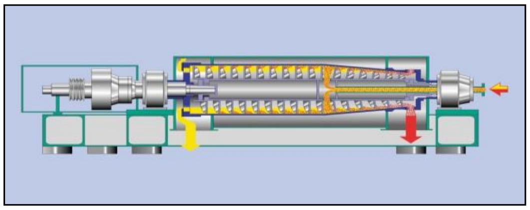
Natural

- Drying beds, Sludge lagoons

Mechanised

- Centrifuges
- Vacuum filters
- Belt presses
- Filter presses
- Dry solids level in the dewatered sludge (%)
- Drying beds up to 45%
- Centrifuges 25-35%
- Belt press 25-40%

6.7 Centrifuge



- Centrifugation is a solids/liquid separation operation forced by the action of a centrifugal force.
- In a first stage, the sludge particles settle at a velocity much higher than would occur under the action of gravity.
- In a second stage, compaction occurs when the sludge loses part of the capillary water under the prolonged action of centrifugation. The cake is removed from the process after this last dewatering stage.

- The semi-continuous feeding of the sludge and relatively lower solids levels in the cake produced by the vertical-shaft centrifuges are some of the reasons for this preference.

6.8 Thermal sludge drying using waste heat from the GasTurbine


Sludge drying with steam Dried sludge

7. INDUSTRIAL WASTEWATER TREATMENT

7.1 Pollutants in industrial waste water

Sector	Major Pollutants
Textiles and leather	BOD, solids, sulfates, dyes, Cyanide and chromium, Lead, Mercury
Iron and steel	BOD, COD, oil, metals, acids, phenols, and cyanide
Pulp and paper	BOD, COD, solids, Chlorinated organic compounds
Chemicals	COD, organic chemicals, heavy metals, SS, and cyanide
The metal-working industries	chromium, nickel, zinc, cadmium, lead, iron and titanium compounds

7.2 Textile effluent treatment methods

Process	Stage	Status	Performance	Limitations
Biodegradation				
Activated sludge	Main treatment	Widely used	Bulk COD removal; partial nitrification	High residual COD, ammonia, colour
Variation of AS like MBBR	Main treatment		Full decolourisation	
Physicochemical treatment				
Coagulation-flocculation	Pre-, main or post-treatment	Extensive use	Almost full decolourisation; water reuse	Unreliable performance; sludge disposal
Adsorption	Pre- or post-treatment	Bench- to full-scale depending on adsorbent	Water reuse with newer adsorbents	Sludge disposal or adsorbent regeneration

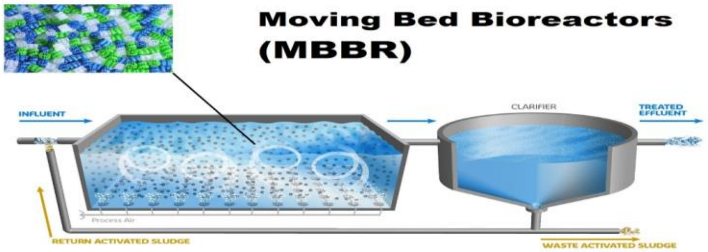
Membrane filtration	Main or post-treatment	Extensive use in South Africa	Reliable performance; water reuse	Concentrate management
Oxidation				
Ozonation	Post-treatment	Full-scale	Full decolourisation; water reuse	Expensive; aldehydes formed
H2O2/UV/ Fe2+	Main treatment	Full scale	Full decolourisation	

7.3 Activated sludge process

- Activated Sludge process is mostly adapted for removing biodegradable organics in industrial wastewater.BOD up to 20mg/l & SS up to 30mg/l is achieved

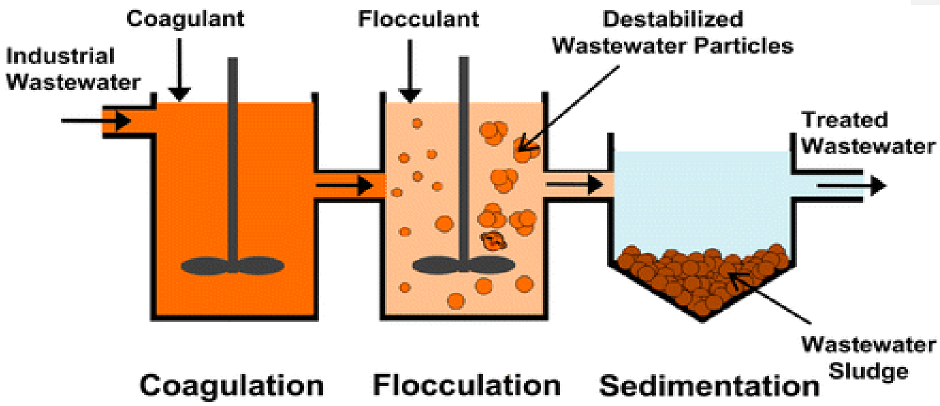
7.4 Moving Bed Biofilm Reactor (MBBR)

- MBBR process is a more modern fixed film process in which the microorganisms grow on plastic media.
- The media are made from high density polyethylene or polypropylene with a diameter of 13 – 25mm, and therefore have a large surface area which helps the biomass to grow inside the surface and are in constant motion due to the compressed air that is blown from under the tank.
- There are already more than 800 MBBR in more than 50 countries. Half treating domestic wastewater and about half treating industrial wastewater.



7.5 Heavy metals & Dyes removal

7.5.1 Hydroxide and Sulphide Precipitation



METAL	Treatment Method
Arsenic	Sulphide precipitation Ferric hodroxide co-precipitation
Cadmium	Hodroxide precipitation at PH-11 Ferric hodroxide co-precipitation Sulphide precipitation
Copper	Hydroxide precipitation Sulphide precipitation
Mercury	Sulphide precipitation Ferric hodroxide co-precipitation
Nickel	Hodroxide precipitation at PH-10
Selenium	Sulphide precipitation
Zinc	Hodroxide precipitation at PH-11
Chromium	ferrous sulphate, sulphur dioxide.

7.5.2 Hydroxide Precipitation

- Most Soluble Heavy Metals Will Precipitate when pH is Raised to a Given Point by Addition of Hydroxide(Sodium Hydroxide, NaOH Caustic Soda. Calcium Hydroxide, Hydrated Lime)

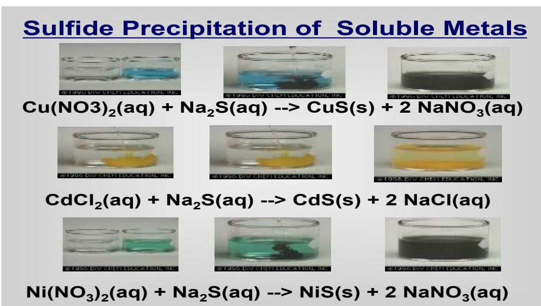
- In this technique the metals are precipitated as insoluble hydroxides and removed by sedimentation and filtration.
- The particles formed by this reaction are removed from solution by settling and/or filtration.
- $Cu(NO_3)_2(aq) + 2\ NaOH(aq) \qquad Cu(OH)_2(s) + 2\ NaNO_3(aq)$

7.5.3 Sulphide Precipitation

Sulfide precipitation with Na_2S(sodium sulphide) is found to be highly effective to obtain a high degree of separation of heavy metals like arsenic and other heavy metals.

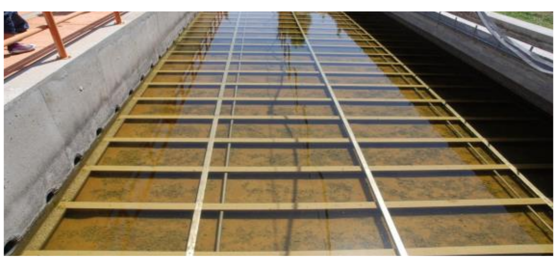
More Costly than OH

May Produce H_2S in Lethal Concentrations



7.5.4 Media filtration

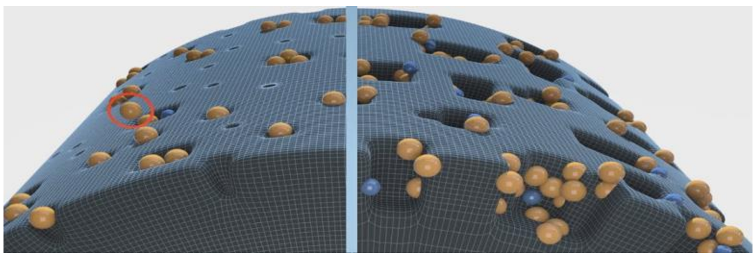
SAND FILTRATION is used as tertiary treatment for TSS and microorganisms



7.5.5 Adsorption of Refractory organics

- Organics, which are difficult or impossible to remove through conventional biological treatment. These materials can be removed by adsorption on activated carbon or synthetic active-solid surface.

- Compounds found in:
- perfumes and cosmetics,
- and used in the manufacture of pharmaceuticals,
- colorants, detergents,
- phenol compounds,



7.5.6 ION EXCHANGE

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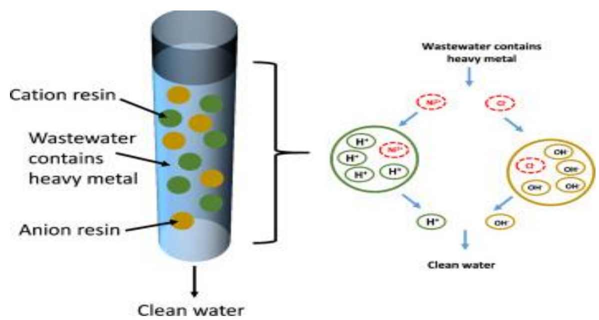
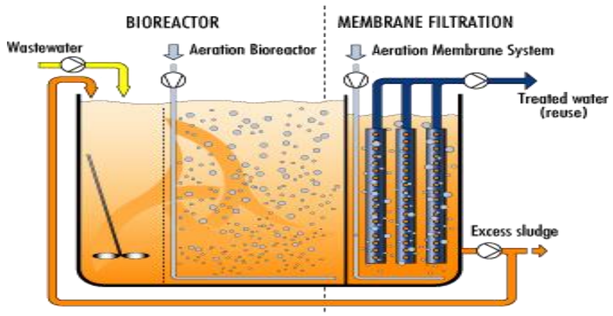


- Ion exchange method has been applied for heavy-metal-containing effluent treatment because of its numerous benefits, such as great removal capacity, higher selectivity for specific heavy metal ions, and rapid kinetics.
- It lessens the main difficulty of chemical precipitation treatment, the disposal of significant amounts of sediments and sludge.
- A resin with hydrogen ions available for exchange will exchange those ions for nickel ions from the wastewater solution.
- The reaction can be written as follows:
- $(R\text{–}SO_3H)_2 + NiSO_4 = (R\text{-}SO_3)_2Ni + H_2SO_4$

7.5.7 Membrane Separation MBR

- Membrane separation benefits include simple operation, less space utilization, less chemical use, and the ability to be effortlessly linked with other separation techniques for enhanced removal efficacy.
- The membrane separation techniques that worked for heavy-metal-containing wastewater are ultrafiltration, nanofiltration, reverse osmosis depending on the size of the element that can be retained.
- MBRs are used for industrial wastes with BOD of 5,000 to 40,000 mg/L.
- There are currently over 1,200 installations and half of them are in industrial applications.



7.5.8 Advanced oxidation processes

- The AOPs show specific advantages over conventional treatment alternatives because they can eliminate non-biodegradable organic components or inorganic contaminants in water and wastewater and avoid the need to dispose of residual sludge.
- H2O2/UV/ Fe2+
- Ozone/UV/ H2O2
- Ozone/Hydrogen peroxide (H2O2)

7.5.9 Hydrogen Peroxide (H2O2)/UV

- Hydrogen peroxide (H2O2) decolorizes of dye compounds.

- The UV-H_2O_2 combination is able to totally destroy the chromophore, the part responsible for its color structures.
- Ferrous ions in an acidic medium, in the presence of H_2O_2, generates free OH radicals as shown below.
- $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\cdot + OH^-$
- Hydroxyl free radical (OH) is a 35% stronger oxidizing agent than O_3.

7.5.10 OZONE/UV/ H2O2

- Chemical processes that employ Ozone (O_3), hydrogen peroxide (H_2O_2) and/or UV light.
- It reduces;
- color,
- oxidizes iron, manganese, cyanide, phenol, benzene, atrazine, nitrobenzene and other pollutants.
- improves taste and odor,
- kills bacteria and viruses (even the chlorine- resistant Polio-virus),

7.5.11 Sodium hypochlorite (NaOCl)

- The active constituent is hypochlorous acid (HOCl).
- The higher the chlorine concentration reaching 150mg/L, the better the effect.
- DE colorization is better at a low acidic pH of 4 – 6.8.

References

- *Metcalf and Eddey Wastewater Engineering treatment and reuse 4rth edition.*
- *Von Sperling "Biological wastewater treatment in warm climate regions*
- *Von Sperling "Activated sludge and aerobic biofilm reactors"*
- *US EPA " Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field,2011"*
- *Wichitra Singhirunnusorn:"A Critical Analysis Of Economic Factors For Diverse Wastewater Treatment Processes: Case Studies In Thailand, University Of California, Los Angeles, 2009)*
- *https://www.melbournewater.com.au/water-data-and-education/learning-resources/water-and-sewage-treatment-plants/western-treatment*
- *Professor Ahmed Saatci President Turkish Water Institute (SUEN)*
- *US EPA "Technology Fact Sheet Trickling Filters"*