Recent Innovative Biological Wastewater Treatment Technologies for Textile Dyeing Wastewater

Fifth International Symposium on Bioremediation and Sustainable Environmental Technologies
15 – 18 April 2019, Baltimore, Maryland

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Major sources of pollution

Domestic Sewage

Industrial wastewater

Agricultural discharge

Textile Industry – Indian Scenario

- **2nd largest sector** in India providing employment and foreign exchange
- Direct employment to **35 million**
- **indirect employment to 50 million**
- 2nd largest producer of cotton fiber in the world
- Tamil Nadu contributes more than **22%** country's export of cotton yarn and fabrics.

14% of exports

Source: Pollution abatement and cleaner technologies, CPCB, 2013

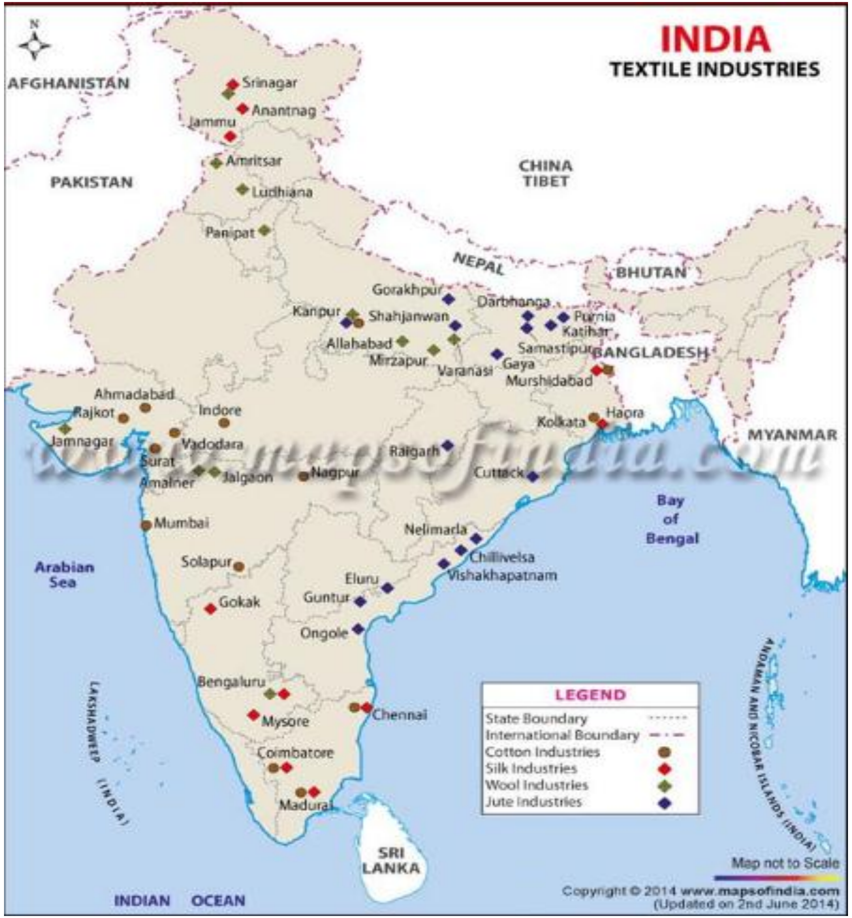
TEXTILE OPERATION

STAGE -1: FIBRE → Spinning → YARN

STAGE -2: YARN → Weaving /Knitting → GREY CLOTH

STAGE - 3: GREY CLOTH → Value Added Bleaching/Dyeing/ Printing (Wet Processing) → FINISHED PRODUCTS

Major Textile Industries in India



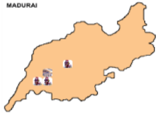
Source : Maps of India

Major textile districts in Tamil Nadu

Major Textile cities

- Coimbatore
- Chennai
- Madurai
- Mysore
- Bangalore
- Ongole
- Gokak
- Guntur
- Eluru
- Solapur
- Mumbai
- Nellimarla
- Chillivelsa
- Vishakapatnam
- Indore
- Vadodara
- Mumbai
- Nagpur
- Jamnagar
- Rajkot
- Panipat
- Ludhiana
- Kanpur
- Ahmedabad
- Allahabad
- Srinagar
- Anantnag
- Kolkata
- Haora
- Varanasi
- Mushidabad
- Amritsar

Coimbatore
Dyeing and knitwear



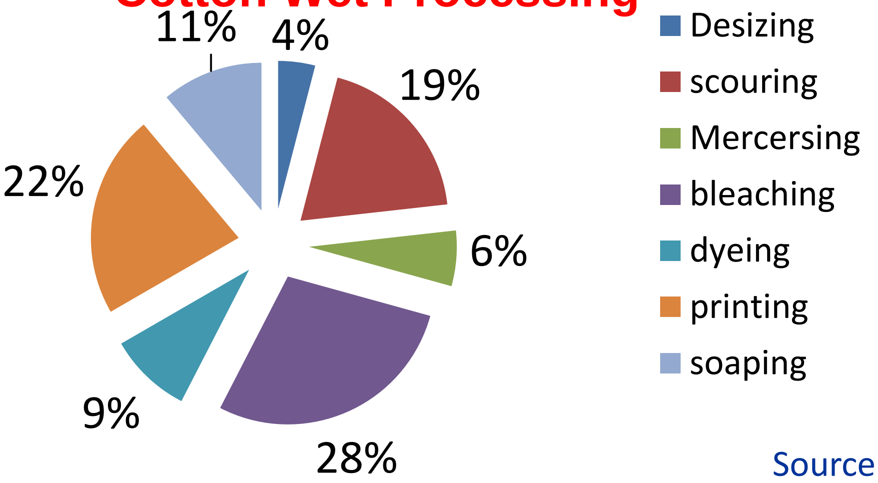
Madurai
Ready made clothes, etc

Tirupur
Banian and export clothes

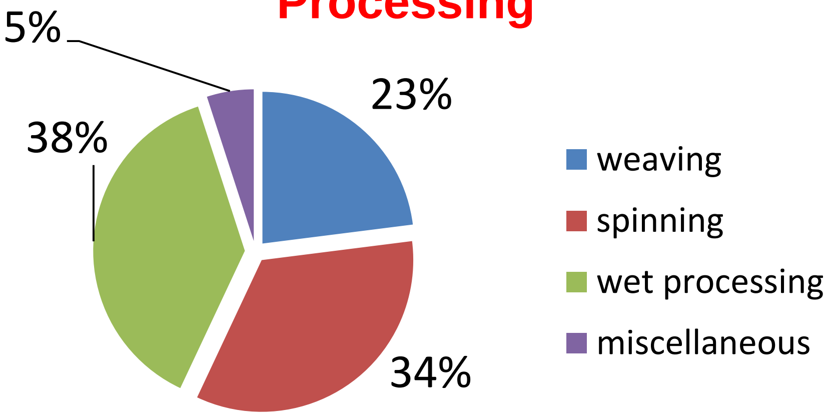
Erode
Dyeing and ready made clothes

Chennai
Exports

Water Consumption In Indian Cotton Wet Processing



Energy Consumption In Wet Processing



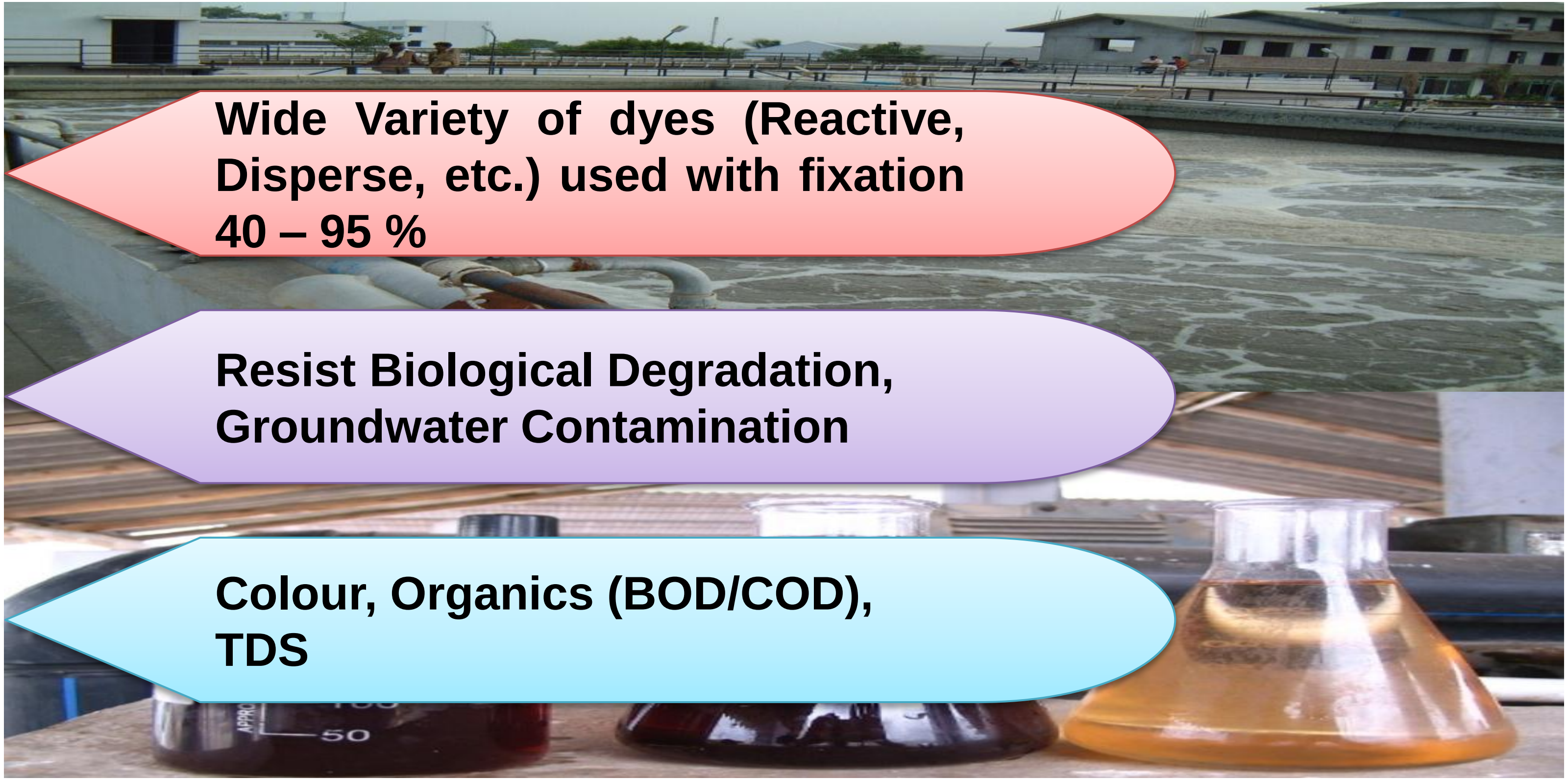
Source: pollution abatement & clean technologies, CPCB, MoEF, 2013

Wet processing is a serious environmental pollution

by 2025, half of the world's population will be living in water-stressed areas.

World health Organization

Causes and Concern



Wide Variety of dyes (Reactive, Disperse, etc.) used with fixation 40 – 95 %

Resist Biological Degradation, Groundwater Contamination

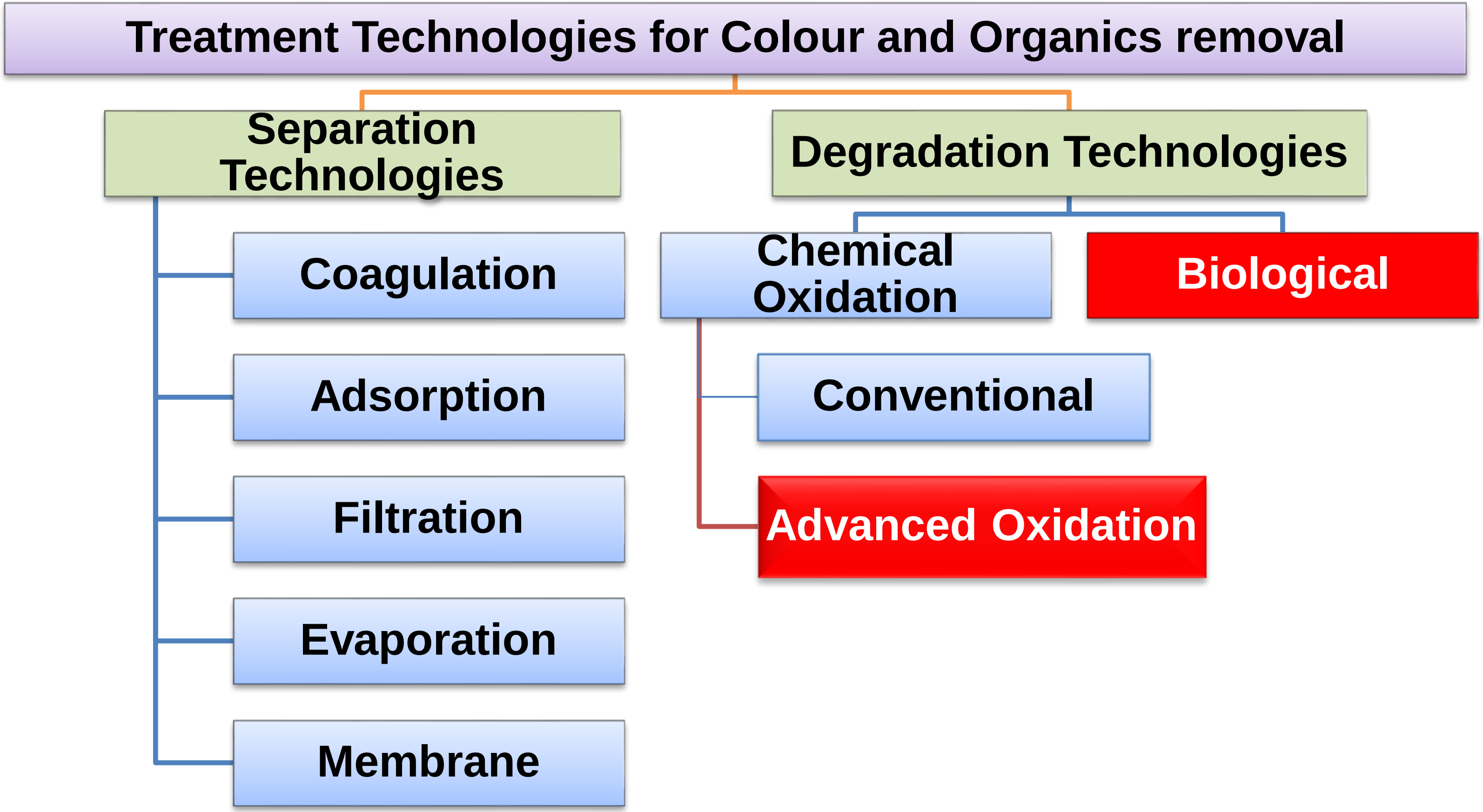
Colour, Organics (BOD/COD), TDS

Our Research

Advanced Oxidation Process

AOP in combination with Biological Treatment

Wastewater Treatment Technologies



Existing Methods and Its Demerits

Intensive treatment is necessary to degrade the dyestuff and reduces the COD from the effluent

Methods	Removal	Demerits
Coagulation, flocculation	Colour	Large amount of sludge generated (10 – 15 tons/day).
Adsorption		Disposal of spent carbon
Chlorine/hypochlorite oxidation		Formation of toxic chlorinated organic substances.
Fenton's reagent		Sludge formation
Biological degradation	BOD, COD	Longer period of acclimitization, slow to degrade, High foot print & Consumes high energy.

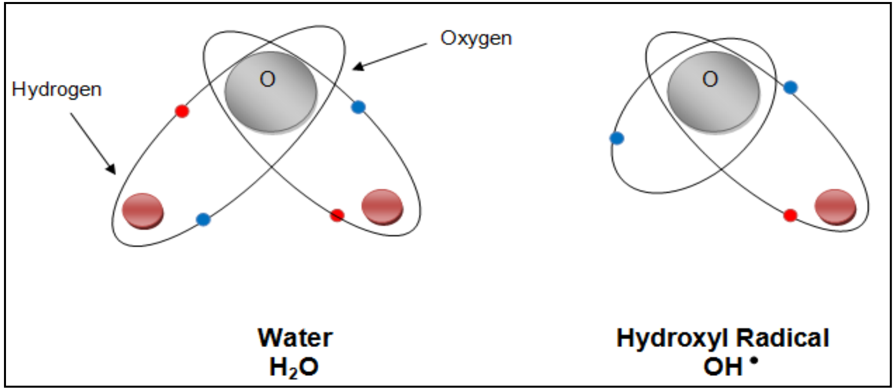
Advanced Oxidation Process

<u>*Definition* by Glaze *et al.* (1987)</u>

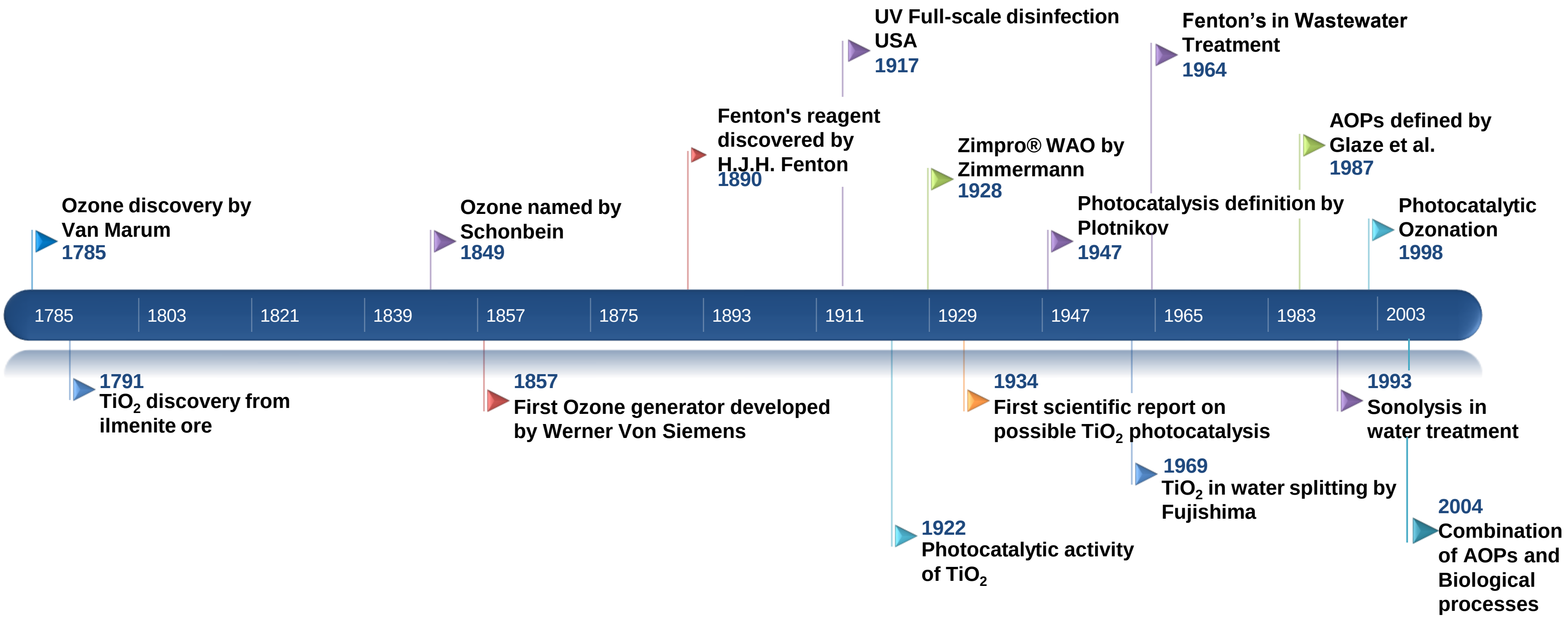
Near ambient temperature and pressure water treatment processes which involve the generation of highly reactive **hydroxyl radical** (HO°)

Hydroxyl radical:

- Powerful, non-selective chemical oxidant
- Reacts with most organic compounds

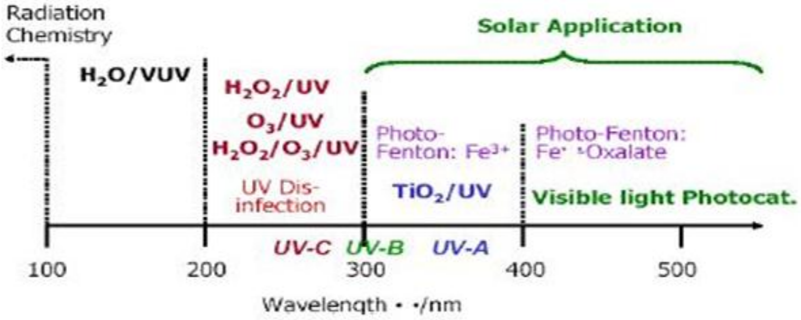


Timeline

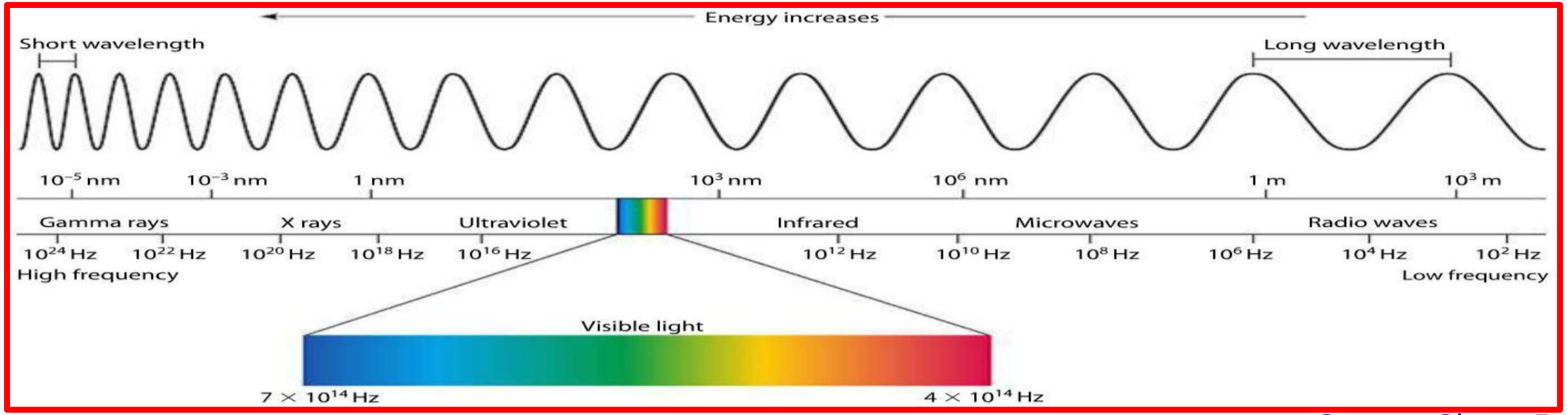


(Source: Thomas Oppenlander (2003); Wikipedia)

Wavelength range of photo-chemical degradation

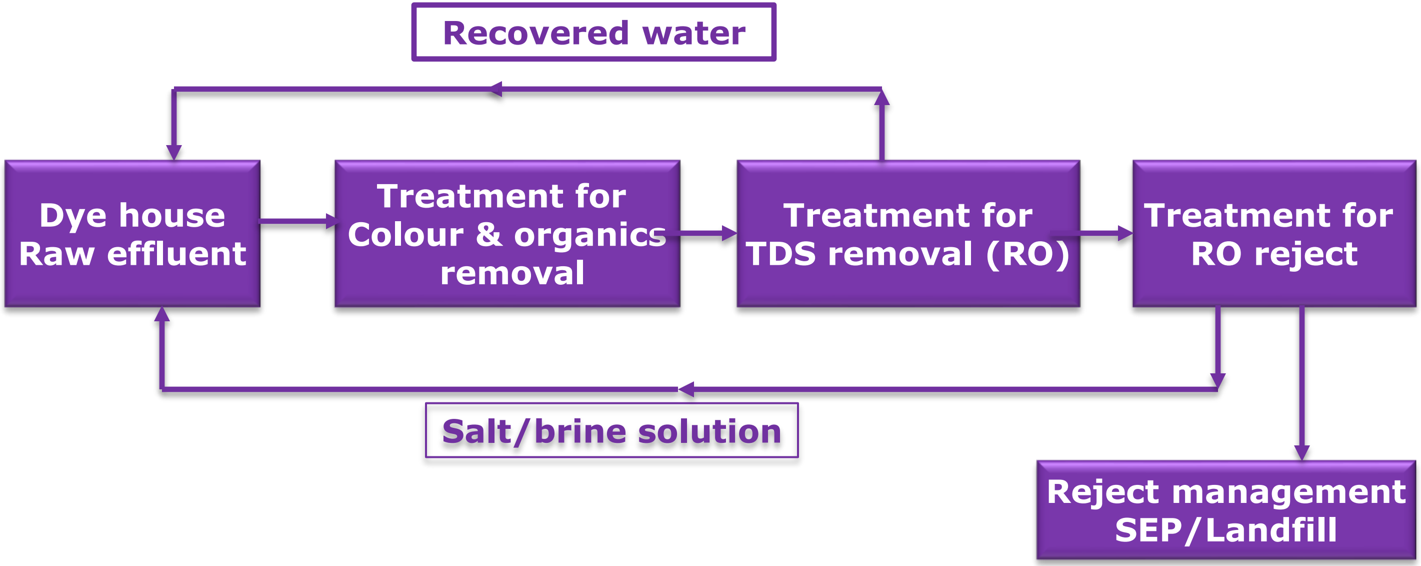


S.No	Processes	Wavelength	Energy (KJ/mol)
1.	UV Photolysis	100 to 400 nm UV-A = 315 to 400 nm UV-B = 280 to 315 nm UV-C = 200 to 280 nm VUV = 100 to 200 nm	299 to 1196 299 to 380 380 to 427 427 to 598 598 to 1196
2.	a. H_2O_2/UV b. $H_2O_2/UV/O_3$ c. $H_2O_2/UV/TiO_2$	254 nm 200 to 300 nm 200 to 300 nm	 427 to 598 427 to 598
3.	O_3/UV	254 nm	
4.	a. Photo-Fenton (Fe^{2+}/ H_2O_2 /UV) b. TiO_2/UV c. $TiO_2/UV/O_3$	180 to 400 nm	299 to 598



Source: Simon Parsons, 2004

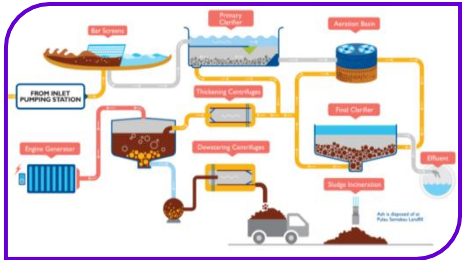
Treatment Scheme for Zero Liquid Discharge System



TNPCB insists to provide ZLD system

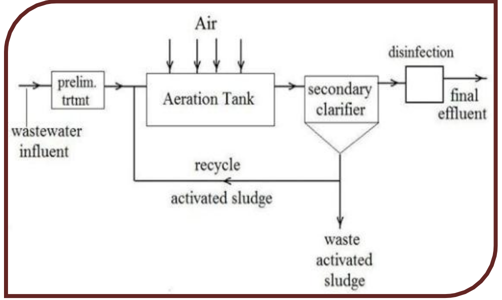
Biological Treatment Systems - Timeline

Dr. G. Fowler, UK - Activated Sludge Process (ASP)



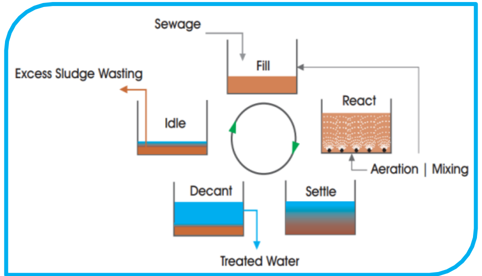
1914

1960



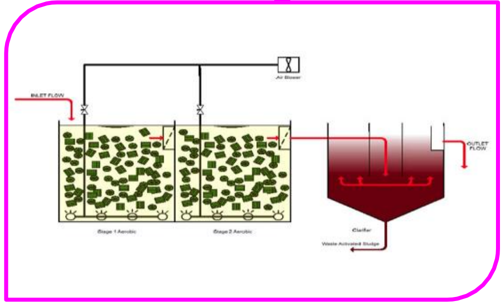
Extended Aeration System

Sequencing Batch Reactor (SBR)



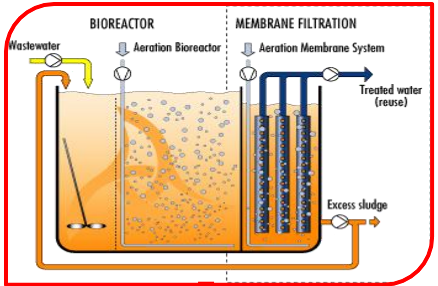
1970

1980



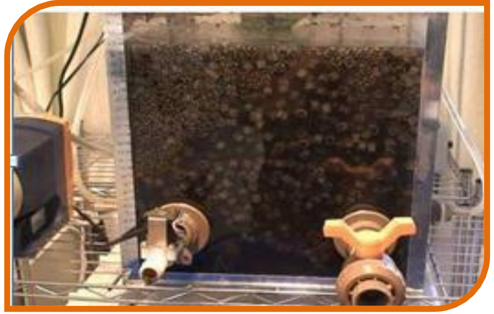
Moving Bed Bio Reactor (MBBR)

Dr. Yamamoto, Japan - Membrane Bio Reactor (MBR)



1989

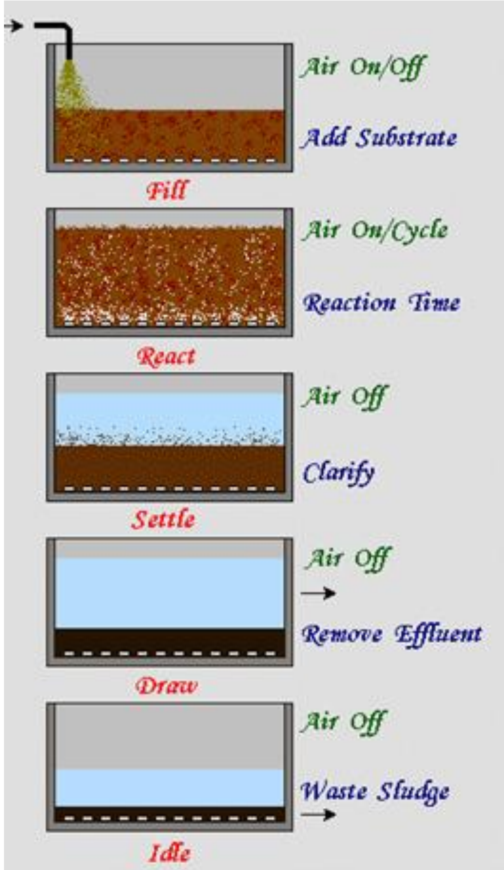
1993



Sequencing Batch Biofilm Reactor (SBBR) (Under Research level)

SBR vs SBBR

Operating sequence of SBR



SBR - Modified Extended aeration system

Suspended growth process

☹ Huge sludge production

☹ Less Sludge Retention Time (SRT)

Sequential Batch Biofilm Reactor (SBBR)

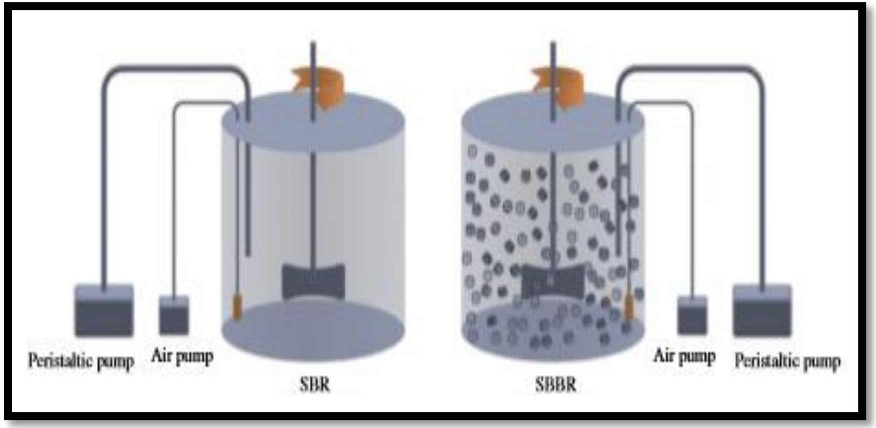
Attached growth process

☺ More biomass formation

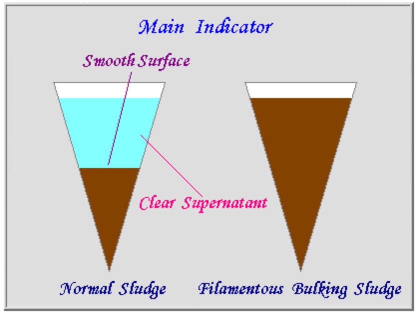
☺ Less sludge production

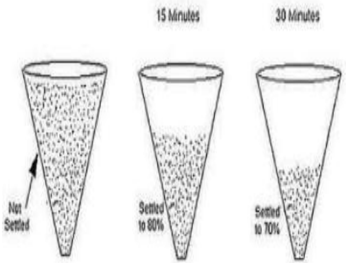
☺ Longer SRT

Source: Nazaroff & Alvarez-Cohen, 2014



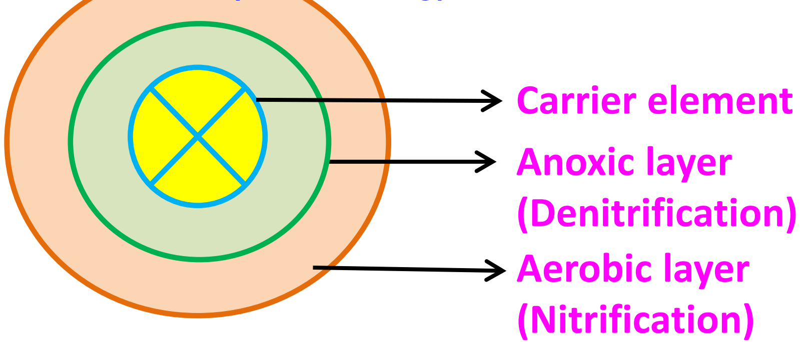
Reactor	Sludge production (g/d)	SVI (mL/g)
SBR	13.5	142
SBBR	6.7	97





SVI - Determines the settling characteristics of sludge.

- Sludge Volume Index (SVI) = 90 to 110 mL/g
- SVI >110 mL/g (Sludge bulking occurs due to growth of filamentous bacteria, leads to poor settling).
- SVI < 90 mL/g (Old, dense & over-oxidised sludge. Induce rapid settling)



Source: Asha Gurruraj & Manoj Kumar, 2015

Existing Technologies – Merits and Demerits

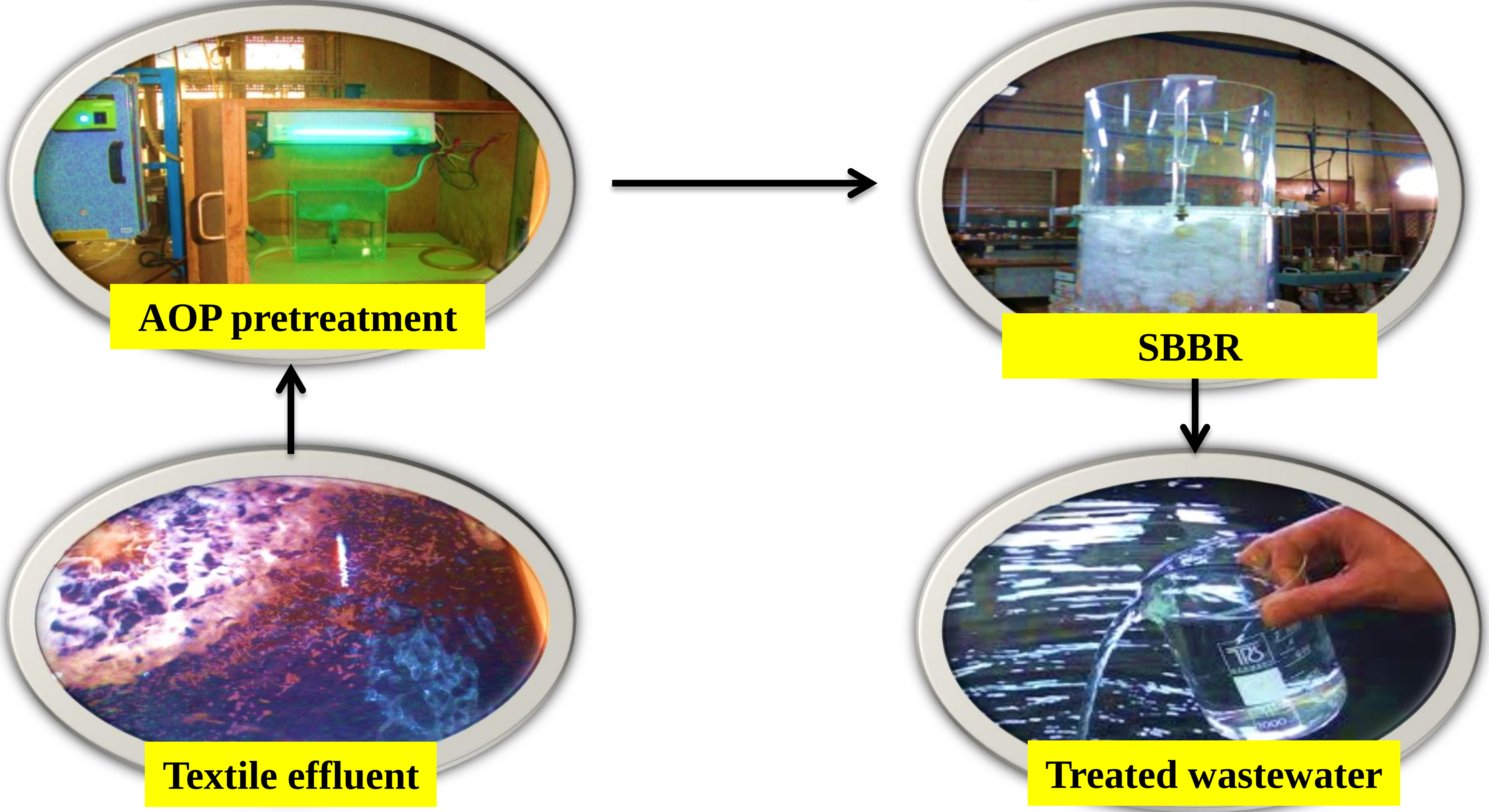
S. No.	Reactor type	Design Criteria	Advantages	Disadvantages
1.	Activated sludge reactor	• MLSS =1500 mg/L to 3000 mg/L • HRT= 4 to 6 hours, • F/M ratio = 0.3 to 0.4 d^{-1} • Recirculation ratio = 0.25 to 0.5	• Requires unskilled labor • Simple and easy to operate	• Large footprint • Minimal nutrients removal Excess bio-sludge production
2.	Sequencing batch reactor	• MLSS =3500 mg/L to 5000 mg/L • Cycle Time= 2.5 to 6 hours, • F/M ratio = 0.05 to 0.3 d^{-1}	• Accommodates large fluctuations • High SRT	• Excess bio-sludge production • Requires skilled labor to operate
3.	Trickling filter	• HLR= 10 to 40 ($m^3/m^2/d$) • OLR = 0.3 to 1(kg BOD/m^3/d) • Recirculation ratio = 0.5 to 0.3	• Requires unskilled labor • Withstands shock loading	• Blockage of filter • Odour and fly nuisance • Requires high capital cost
4.	Rotating biological contactor	• HLR= 0.03 to 0.08 ($m^3/m^2/d$) • OLR = 5 to 16 (g BOD/m^2/d) • HRT = 1.5 to 4 hours	• Maintains aerobic and anoxic condition on the disc • Short contact time due to large active surface area	Shaft bearings and mechanical units require frequent maintenance
5.	Fluidized bed biofilm reactor (or) Moving bed biofilm reactor		• Lesser aeration tank volume • Higher SRT	• Control of bio-carriers is difficult • Less nutrient removal
6.	Membrane bio-reactor		• Small footprint • Produce RO feed water quality	• Requires high capital and operating cost • Membrane fouling

Typical process design parameters

S.No.	Parameters	Design Criteria	
		SBR (Intermittent flow and Intermittent Decant)	Conventional ASP
1.	F/M Ratio (days^{-1})	0.05 - 0.3	0.3 - 0.4
2.	Sludge age (days)	4 - 20	5 - 8
3.	Sludge yield (kg of dry solids/Kg of BOD)	0.75 – 1.0	1.0
4.	MLSS (mg/L)	3500 - 5000	1500 - 3000
5.	Cycle time/Aeration time (h)	2.5 - 6	4 - 6
6.	Settling time (h)	> 0.5	1.5 to 2.5

Source: CPHEEO Manual, November 2013

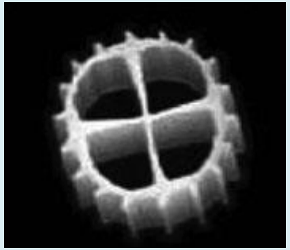
Scope of the study



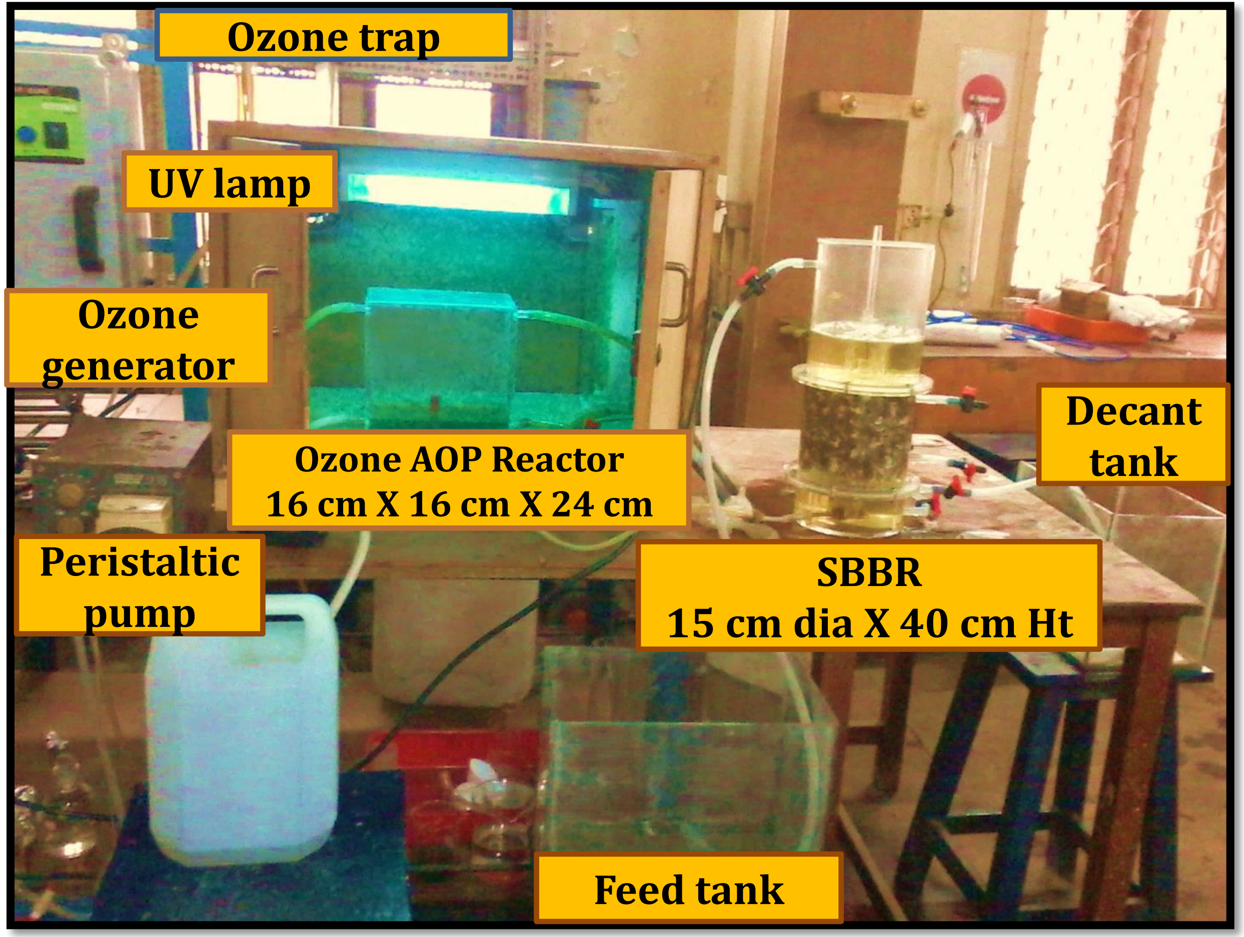
Literature review – SBBR system

Type of wastewater	Experimental conditions	Media specifications	Findings	Reference
Diary wastewater 	Fill – 2 h React - 19 h Settle - 2 h Draw & Idle – 1 h	**Plastic bio-ball** (2.5cm dia) • Filling - 40%, • Surface area – 12000 m^2/m^3 • Density of each ball – 0.96 g/cm^3	COD removal = 99% TKN rremoval = 78%	Ahmed Nazem et al., 2014
Domestic wastewater 	Fill – 1 h Anaerobic – 17 h Aerobic – 6 h Settle - 1 h Decant – 1 h	**Polyurethane foam** 1cm X 1cm X 1cm	COD removal = 99%	Asha Gururaj & B Manoj Kumar, 2015
Dairy wastewater 	Fill – 2 h React – 20 h Settle - 1.5 h Draw - 0.5	**Rayon fibre** • 75mm long,0.07mm dia, • Specific surface area – 2200 m^2/m^3.	COD removal = 90 - 97%	Abdulgader et al., 2009

Literature review – SBBR system

Type of wastewater	Experimental conditions	Media specifications	Findings	Reference
Sewage wastewater 	Fill – 30 min React – 4 h Settle – 1 h Draw – 30 min	**K1 Kaldnes** • Polyethylene shaped like small cylinder with dia 9.1mm & length 7.2mm • Specific gravity 0.96g/cm^3, surface area 500m^2/m^3.	COD removal • 40% media = 89% • 50% media = 91% • 60% media = 94%	Ahmet Aygun et al., 2014
Swine wastewater 	Fill – 5 min Anaerobic - 1.5 h Aeration – 6 h Settle – 20 min Draw – 5 min	Activated carbon fiber Ht-40cm & 12000 carbon filler threads	COD removal = 98% TN = 97% TP = 96%	Reti Hai, Yiqun He Xiaohui Wang, Yuan Li et al., 2015

Experimental Setup



Material – Polyester fiber
Yarn diameter – 0.2 cm
Fiber density – 1.4 g/cm^3
Specific surface area - 600 m^2/m^3
Cost – Rs. 150/kg

Characteristics of Raw Textile Dyeing Effluent

Parameters		IWW 1	IWW 2	IWW 3
Color	436 nm	0.866	0.978	0.701
	525 nm	0.955	0.715	0.587
	620 nm	0.504	0.623	0.678
pH		9.2	9.4	8.7
TDS (mg/L)		6240	6720	6440
TSS (mg/L)		210	290	280
COD (mg/L)		925	980	800
BOD_5 (mg/L)		220	285	254
BOD_5/COD		0.23	0.29	0.31

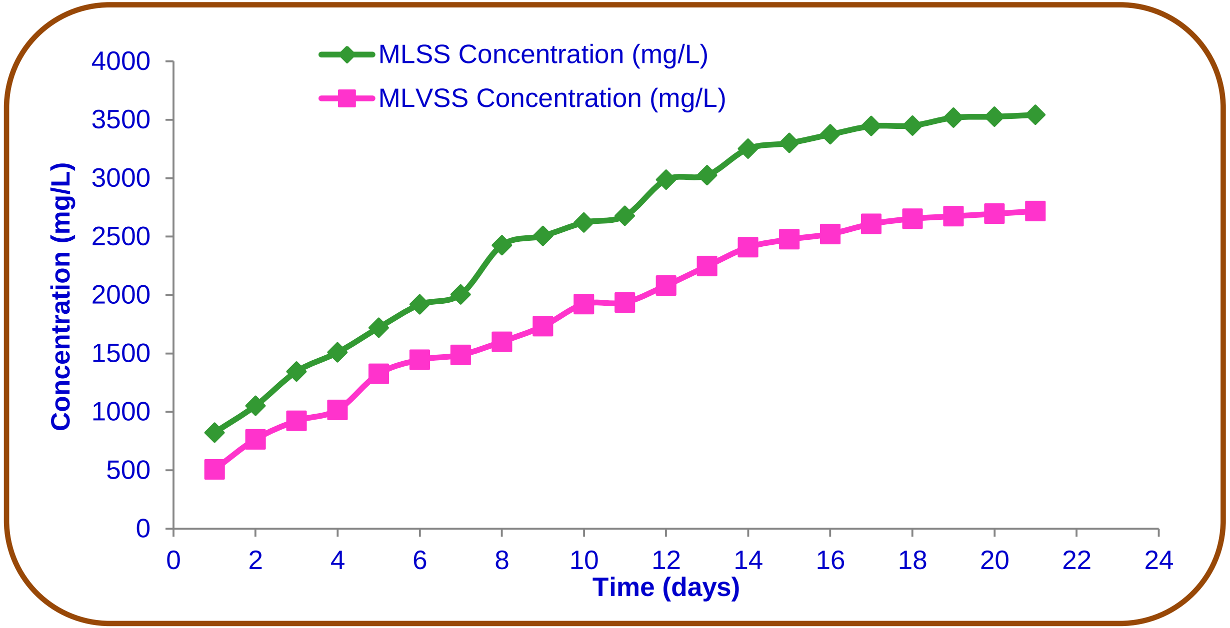
Characteristics of AOP Treated Wastewater

Parameters		IWW 1	IWW 2	IWW 3	Average removal efficiency (%)		
					IWW1	IWW2	IWW3
Color	436 nm	0.130	0.108	0.030	85	87	90
	525 nm	0.115	0.086	0.068	88	90	91
	620 nm	0.101	0.050	0.070	86	91	91
COD(mg/L)		470	540	460	49	45	43
BOD(mg/L)		210	240	180	18	16	17
BOD/COD		0.40	0.44	0.45	-	-	-

Experimental Conditions
Ozone dosage – 150 mg/L; H_2O_2 dosage - 150 mg/L; Contact time - 120 minutes

- Decolourisation was due to the rapid destruction of the conjugated double bonds in the chromophore groups of dyes and forms smaller molecules (intermediates), resulting in colour removal (Nese and Filiz, 2014).
- Most efficient for colour reduction was the combination of O_3+ H_2O_2 + UV with Ozone dosage of 500 mg/h and 100 mg/L of H_2O_2 the reduction of colour was 86% at 280 minutes (Aleksandra *et al*., 2012).

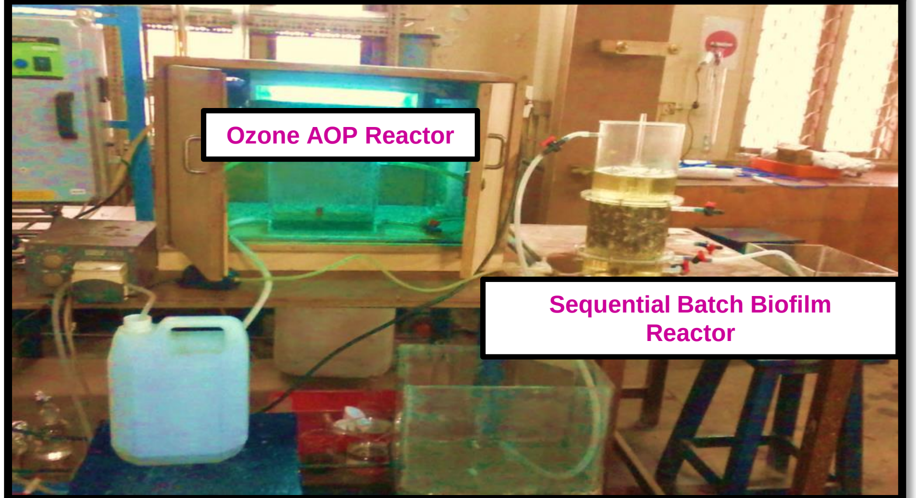
MLSS Vs Time

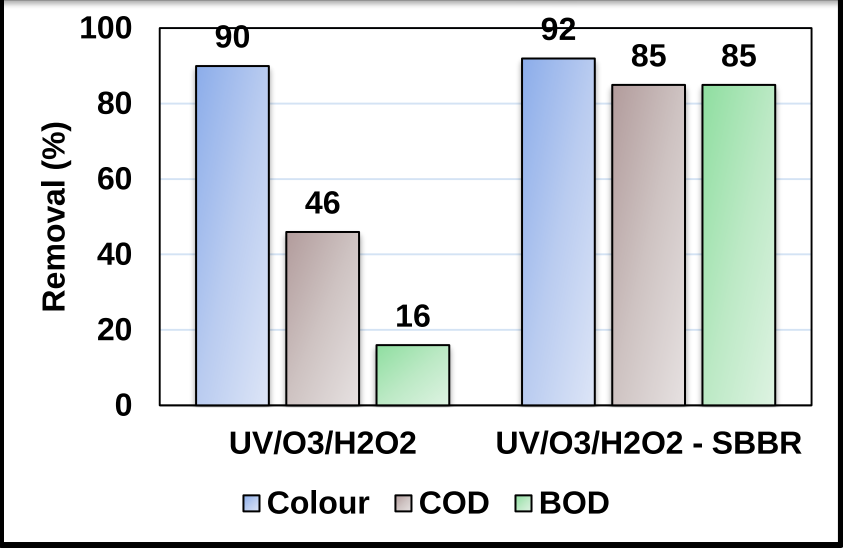


- Biofilm formation and biomass adhesion depends on the hydrodynamic conditions in the reactor and geometry of the bio-carrier.
- Bio-carrier having higher internal surface area protects the biomass from erosion and abrasion detachment (Matos et al., 2008).

Textile Dyeing Wastewater Treatment

Experimental Setup - $UV/O_3/H_2O_2$ - SBBR



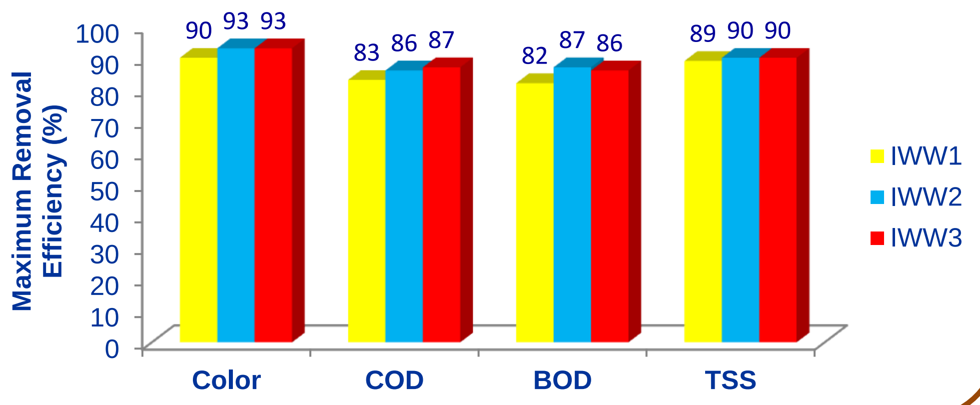


EXPERIMENTAL CONDITIONS:
Volume = 5 L; COD = 800 - 980 mg/L; BOD_3= 220 – 285 mg/L; O_3 dose = 150 mg/L; H_2O_2 dose = 150 mg/L; Contact time: AOP = 2 h; SBBR = 6 h

- Rough surface of fibre thread beneficial to strong adsorption and growth of micro-organisms.
- Reactor volume decreased as the thread serve as filter media to minimize the concentration of suspended solids (Jin et al., 2012).

Performance of lab-scale reactor studies

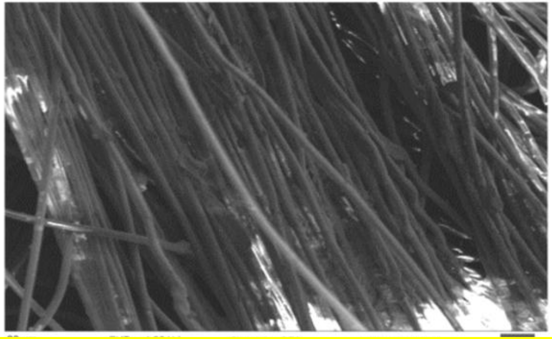
Parameters		IWW 1			IWW 2			IWW 3		
		Raw WW	After AOP	After SBBR	Raw WW	After AOP	After SBBR	Raw WW	After AOP	After SBBR
Colour	436 nm	0.866	0.164	0.130	0.978	0.127	0.068	0.701	0.070	0.049
	525 nm	0.955	0.118	0.096	0.715	0.072	0.064	0.587	0.053	0.052
	620 nm	0.504	0.081	0.065	0.623	0.063	0.056	0.678	0.061	0.047
COD (mg/L)		925	470	157	980	540	137	800	460	105
BOD (mg/L)		220	210	40	285	240	36	254	180	35
TSS (mg/L)		210	180	22	290	270	30	280	250	20



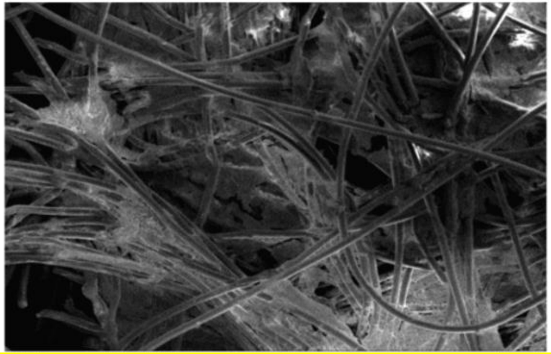
SBBR (with and without pretreatment)

Parameters		Raw IWW	SBBR	% Removal	AOP + SBBR	% Removal
Colour	436 nm	0.701	0.561	22	0.049	93
	525 nm	0.587	0.376	37	0.052	91
	620 nm	0.678	0.427	38	0.047	93
COD (mg/L)		800	384	52	105	87
BOD (mg/L)		254	105	58	35	86
SS (mg/L)		280	98	65	20	92
Specific sludge production ($kgTSS/kgCOD_{removed}$)		-	0.24	-	0.03	-

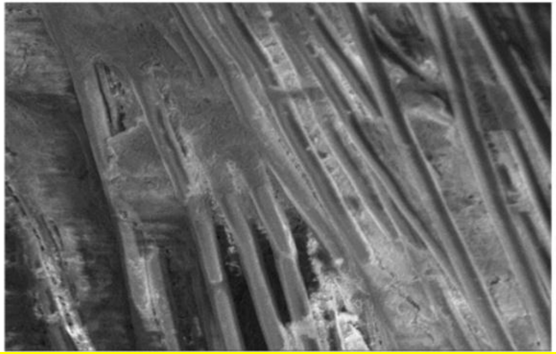
Characterization of biomass – SEM Images



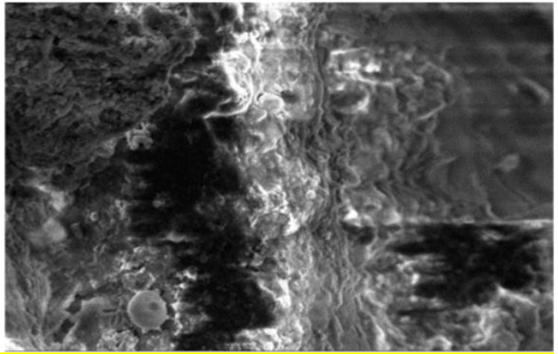
Virgin Fiber



10th day



20th day



30th day

- Presence of bio-carriers suppress the excessive growth of filamentous microorganisms due to **physical cut or breakdown of filaments by particle to particle collision** (Maria Matos et al., 2010).
- Slimy layer - responsible for the oxygen and organic diffusion to the microbial cell (Reti Hai at al., 2014).
- Bacillus shaped micro-organisms dominates in the biomass.

Conclusion

- AOPs can degrade almost all recalcitrant pollutants and emerging contaminants according to their suitability.
- As the ZLD scheme has become mandatory, AOPs can be adopted in IETPs/CETPs for enhancing the treatment efficiency.
- Combination of AOPs with biological treatment systems can be adopted for complete degradation of organic compounds.
- SBBR with textile fabric material – Fixed attached growth system – Avoids difficulty in handling the bio-carrier in the system.
- Significant cost reduction can be done by adopting AOP as pretreatment for improving the biodegradability of recalcitrant wastewater.

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