Industrial Waste Water Treatment

Unit 5

Outline

- Water
- Water availability in the earth
- Distribution of available water in the earth
- Importance of industrial wastewater treatment
- Characteristics of waste water
- Constituents of concern in Industrial wastewater
- Various tests for wastewater
- Waste water treatment levels
- Advance waste water treatment methods

Water

- Water is a transparent and nearly colourless liquid
- Most essential constituent for living organisms in the earth
- The molecular formula for water is H_2O – One oxygen and two Hydrogen atoms
- It also occurs in nature as *snow, glaciers, icepacks and icebergs, clouds, fog, dew, aquifers, and atmospheric humidity*.

“Life will not exist without water in our Mother Earth” – Anonymous

Distribution of available water in the earth

Salt water dominates

97.5%

Salt Water

About 97.5% of all water on earth is salt water

Most fresh water is unattainable

2.5%

Fresh water

Only 2.5% of all the water on Earth is Fresh water

Source: FAO, 2009

Distribution of Water

Most fresh water is unattainable

2.5%

Fresh water

Only 2.5% of all the water on Earth is Fresh water

Frozen icecaps

70%

Polar Ice caps

Around 70% of fresh water is frozen in Antarctica and green land icecaps

Underground

30%

Underground

Most of the remaining fresh water lies too deep underground

Source: FAO, 2009

?%

is available for

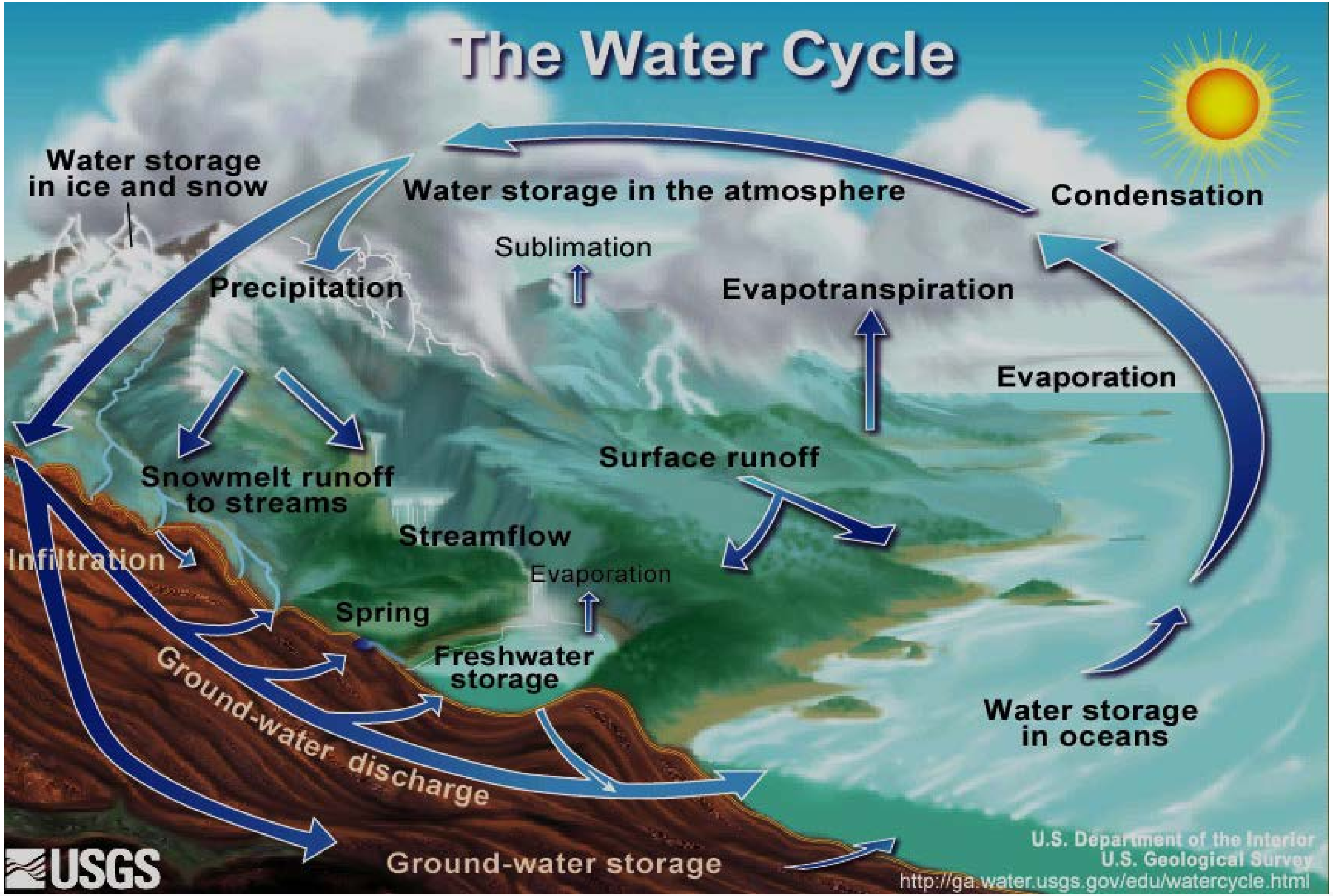
Human Consumption

<1%

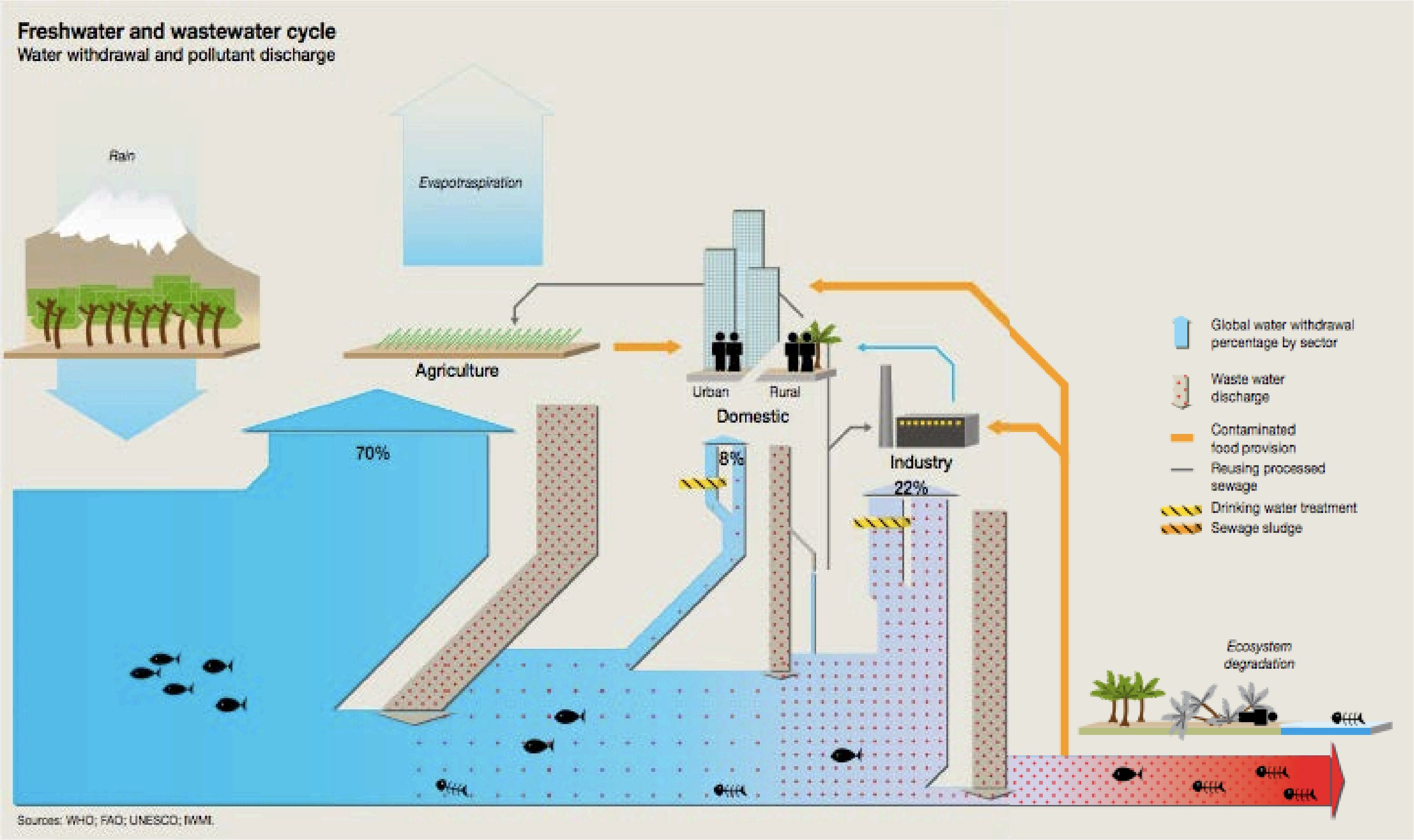
is available for

Human Consumption

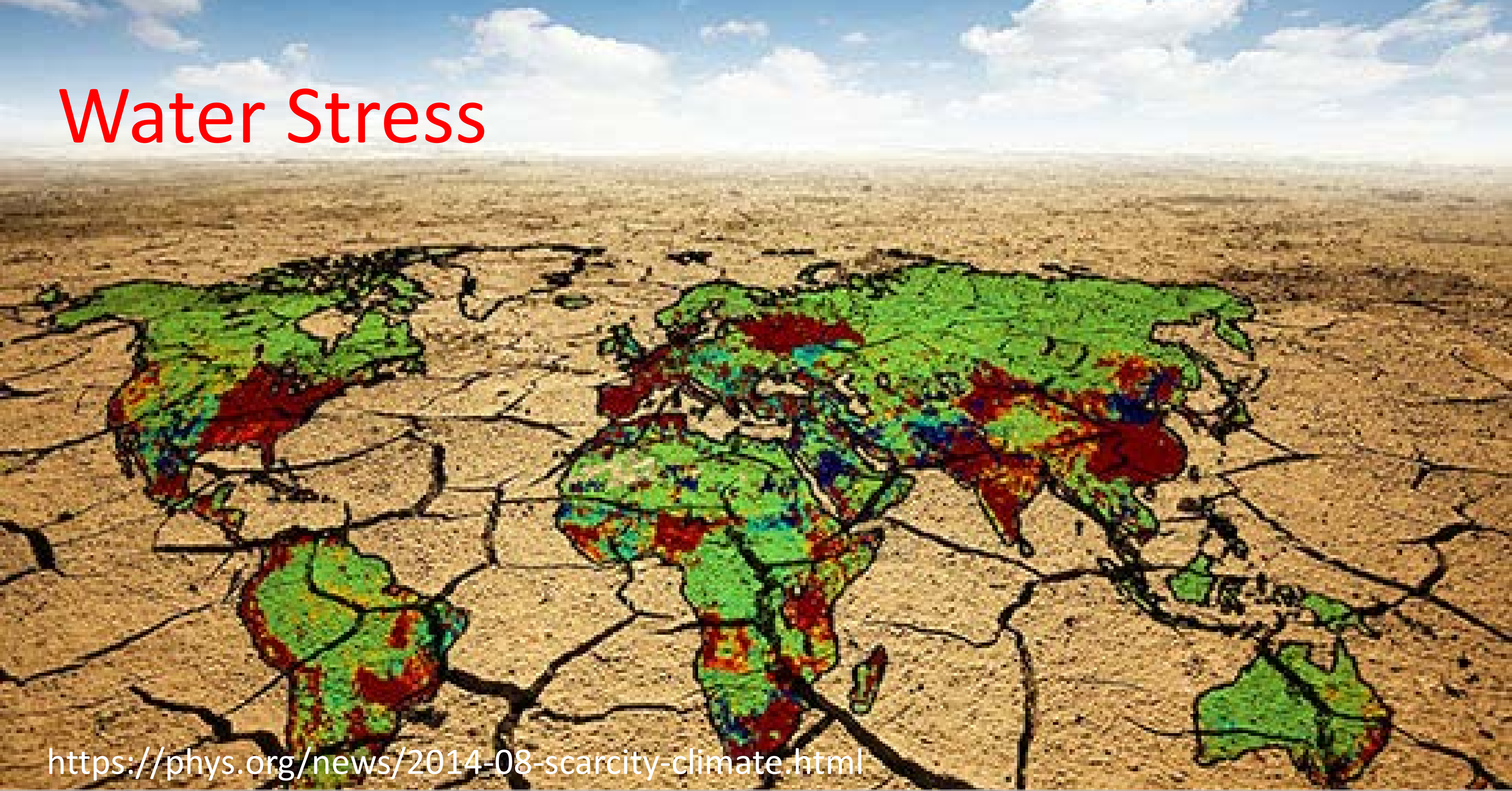
Water cycle


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

Water cycle


Freshwater and wastewater cycle
Water withdrawal and pollutant discharge
Rain
Evapotraspiration
Agriculture
Urban
Rural
Domestic
Industry
70%
8%
22%
Global water withdrawal percentage by sector
Waste water discharge
Contaminated food provision
Reusing processed sewage
Drinking water treatment
Sewage sludge
Ecosystem degradation
Sources: WHO; FAO; UNESCO; IWMI.

Water Stress



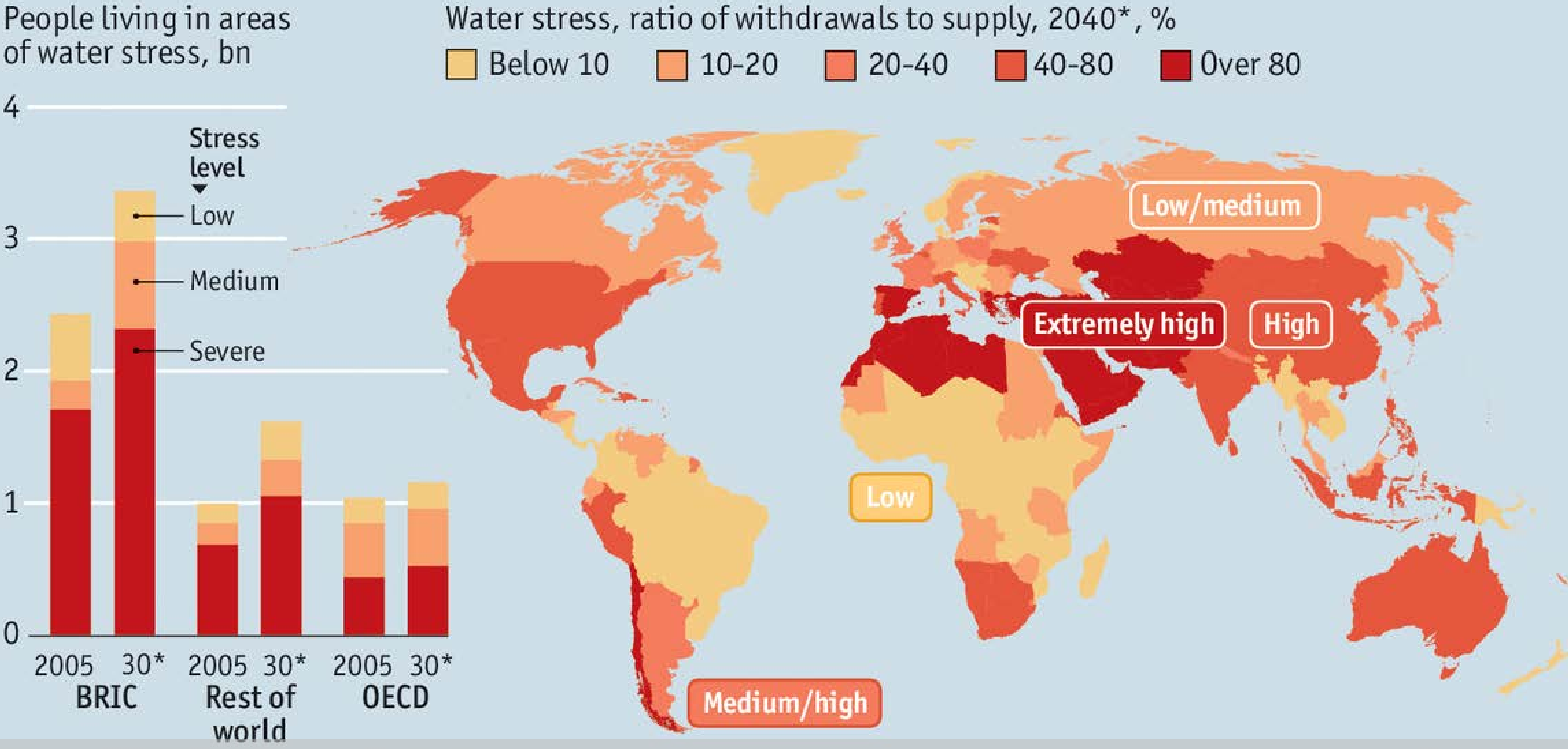
https://phys.org/news/2014-08-scarcity-climate.html

Water stress occurs when the demand for **water** exceeds the available amount during a certain period or when poor quality restricts its use.

Water stress causes deterioration of fresh **water** resources in terms of quantity

Water stress — European Environment Agency
https://www.eea.europa.eu/themes/water/wise-help-centre/glossary-definitions/water-stress

Water pressure - World wide



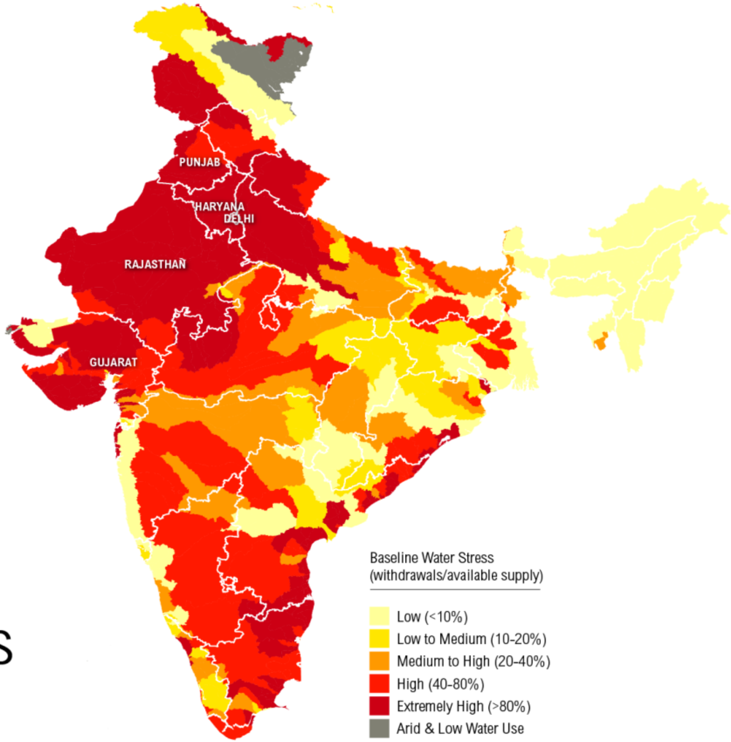
Sources: OECD; World Resources Institute

*Forecast


1.1 billion
The number of people worldwide — 1 in every 6 — without access to clean water
Really we need to think?

Water Stress – India

54%
of India
Faces
High to
Extremely
High
Water Stress

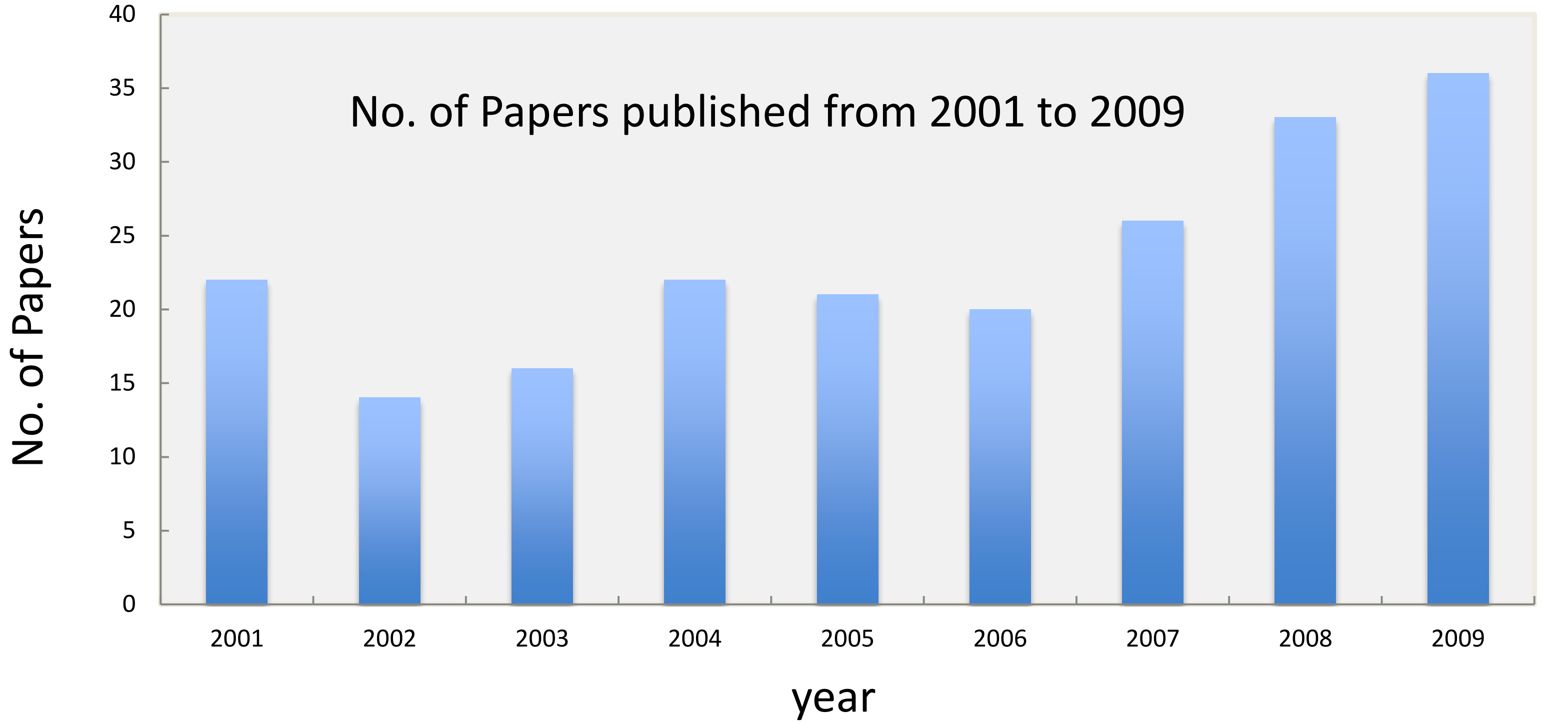


WORLD RESOURCES INSTITUTE


BLUE PLANET
RUN
THE RACE TO PROVIDE SAFE
DRINKING WATER TO THE WORLD
INTRODUCTION BY ROBERT REDFORD
CREATED BY RICK SMOLAN
AND JENNIFER ERWITT


Industrial Water Pollution

Industrial water treatment - research database



Source: Web of Science

- Industrial wastewaters vary enormously in composition, strength and volume from industry to industry and facility to facility within an industry
- Some wastewaters may be acidic or alkaline; contain oxygen depleting organic materials, nutrients (e.g. phosphorous and nitrogen) that can cause eutrophication.
- Suspended solids that can settle in receiving waters causing oxygen consuming sludge deposits; be aesthetically unacceptable because of colour, taste, odour or hazardous (toxic) components.

- Therefore, it is essential to determine the characteristics (physical, chemical and biological) of industrial wastewater.

Water is characterized in terms of its

Physical, Chemical and Biological Composition

Test used to asses the

constituents present in water

Characteristics of waste water – Physical

Test[b]	Abbreviation/ definition	Use or significance of test results
Physical characteristics		
Total solids	TS	To assess the reuse potential of a wastewater and to determine the most suitable type of operations and processes for its treatment
Total volatile solids	TVS	
Total fixed solids	TFS	
Total suspended solids	TSS	
Volatile suspended solids	VSS	
Fixed suspended solids	FSS	
Total dissolved solids	TDS (TS − TSS)	
Volatile dissolved solids	VDS	
Total fixed dissolved solids	FDS	
Settleable solids		To determine those solids that will settle by gravity in a specified time period
Particle size distribution	PSD	To assess the performance of treatment processes
Turbidity	NTU[c]	Used to assess the quality of treated wastewater
Color	Light brown, gray, black	To assess the condition of wastewater (fresh or septic)
Transmittance	% T	Used to assess the suitability of treated effluent for UV disinfection

Characteristics of waste water – Physical

Test[b]	Abbreviation/ definition	Use or significance of test results
Odor	TON[d]	To determine if odors will be a problem
Temperature	°C or °F	Important in the design and operation of biological processes in treatment facilities
Density	ρ	
Conductivity	EC	Used to assess the suitability of treated effluent for agricultural applications

Characteristics of waste water – Chemical (Inorganic)

Test[b]	Abbreviation/ definition	Use or significance of test results
Inorganic chemical characteristics		
Free ammonia	NH_4^+	Used as a measure of the nutrients present and the degree of decomposition in the wastewater; the oxidized forms can be taken as a measure of the degree of oxidation
Organic nitrogen	Org N	
Total Kjeldahl nitrogen	TKN (Org N + NH_4^+)	
Nitrites	NO_2^-	
Nitrates	NO_3^-	
Total nitrogen	TN	
Inorganic phosphorus	Inorg P	
Total phosphorus	TP	
Organic phosphorus	Org P	

Test[b]	Abbreviation/ definition	Use or significance of test results
Inorganic chemical characteristics (continued)		
pH	$pH = -\log[H+]$	A measure of the acidity or basicity of an aqueous solution
Alkalinity	$\Sigma HCO_3^- + CO_3^{-2} + OH^- - H+$	A measure of the buffering capacity of the wastewater
Chloride	Cl^-	To assess the suitability of wastewater for agricultural reuse
Sulfate	SO_4^{-2}	To assess the potential for the formation of odors and may impact the treatability of the waste sludge
Metals	As, Cd, Ca, Cr, Co, Cu, Pb, Mg, Hg, Mo, Ni, Se, Na, Zn	To assess the suitability of the wastewater for reuse and for toxicity effects in treatment. Trace amounts of metals are important in biological treatment
Specific inorganic elements and compounds		To assess presence or absence of a specific constituent
Various gases	O_2, CO_2, NH_3, H_2S, CH_4	The presence or absence of specific gases

Characteristics of waste water – Chemical (Organic)

Test[b]	Abbreviation/ definition	Use or significance of test results
Organic chemical characteristics		
Five-day carbonaceous biochemical oxygen demand	$CBOD_5$	A measure of the amount of oxygen required to stabilize a waste biologically
Ultimate carbonaceous biochemical oxygen demand	UBOD (also BOD_u, BOD_L)	A measure of the amount of oxygen required to stabilize a waste biologically
Nitrogenous oxygen demand	NOD	A measure of the amount of oxygen required to oxidize biologically the nitrogen in the wastewater to nitrate
Chemical oxygen demand	COD	Often used as a substitute for the BOD test
Total organic carbon	TOC	Often used as a substitute for the BOD test
Specific organic compounds and classes of compounds	MBAS[e], CTAS[f]	To determine presence of specific organic compounds and to assess whether special design measures will be needed for removal

Test[b]	Abbreviation/ definition	Use or significance of test results
Biological characteristics		
Coliform organisms	MPN (most probable number)	To assess presence of pathogenic bacteria and effectiveness of disinfection process
Specific microorganisms	Bacteria, protozoa, helminths, viruses	To assess presence of specific organisms in connection with plant operation and for reuse
Toxicity	TU_a and TU_c	Toxic unit acute, Toxic unit chronic

In general the two important characteristics of industrial wastewaters is the BOD and COD apart from the characterises that are discussed previously.

BOD – Biological Oxygen Demand or Biochemical Oxygen Demand

$(BOD)_5$ – 5day Biological Oxygen Demand

COD – Chemical Oxygen Demand

BOD – Biological Oxygen Demand or Biochemical Oxygen Demand

- It is the amount of oxygen used by the microbes in the stabilization of a decomposable organic waste material under aerobic (presence of air) conditions.
- The demand will be the oxygen required for the oxidation of organic (or carbonaceous materials as given below:

$$Organic\ matter + O_2 \xrightarrow{Aerobic\ microbes} CO_2 + H_2O + NH3 + New\ cells + Energy + some\ other\ products$$

BOD – Biological Oxygen Demand or Biochemical Oxygen Demand

- Since the amount of oxygen varies with the length of the time and the temperature, the standard test for BOD is for 5 days at 20 °C and the BOD value yields is referred to as the five day biochemical oxygen demand $(BOD)_5$

COD – Chemical Oxygen Demand

- BOD test requires 5 days duration; and in many cases, it is desired to have rapid test in industrial wastewater treatment. Therefore, COD test is desired on such cases.
- The Chemical Oxygen demand (test) consists of oxidizing the sample (wastewater containing organic matter) with strong oxidizing agent, potassium dichromate and determining the amount of potassium dichromate used. Then the oxygen required in the chemical oxidation can be determined.

Constituents of concern in waste water

Principal Constituents of concern in Industrial wastewater treatment

Constituent	Reason for importance
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms that may be present in wastewater
Nutrients	Both *nitrogen and phosphorus*, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater

Principal Constituents of concern in Industrial wastewater treatment

Constituent	Reason for importance
Priority pollutants	Organic and inorganic compounds selected on the basis of their known or suspected carcinogenicity, mutagenicity, teratogenicity, or high acute toxicity. Many of these compounds are found in wastewater
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols, and agricultural pesticides
Heavy metals	Heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is to be reused
Dissolved inorganics	Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused

Levels of wastewater Treatment

Treatment level	Description
Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment operations, processes, and ancillary systems
Primary	Removal of a portion of the suspended solids and organic matter from the wastewater
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater. Typically accomplished by chemical addition or filtration
Secondary	Removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection is also typically included in the definition of conventional secondary treatment
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus)
Tertiary	Removal of residual suspended solids (after secondary treatment), usually by granular medium filtration or microscreens. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition

Treatment level	Description
Advanced	Removal of dissolved and suspended materials remaining after normal biological treatment when required for various water reuse applications

Treatment Methods employed

- Physical – Screens, Coarse solids reducers, Grit separators, Flow equalizers, Sedimentation, Clarifiers - Mixing, flocculation, Coagulation, Filters – Sand Filtration, Membrane separations, and Adsorption
- Chemical – Ion exchange, Precipitation (oxidation and reduction)
- Biological Methods (Activated sludge, Aerobic and Anaerobic digestion)

Advanced Treatment Methods employed

- Physical - Membrane separation
- Chemical – Ion exchange Precipitation /Advanced chemical oxidation
- Biological process – activated sludge, aerobic and anaerobic

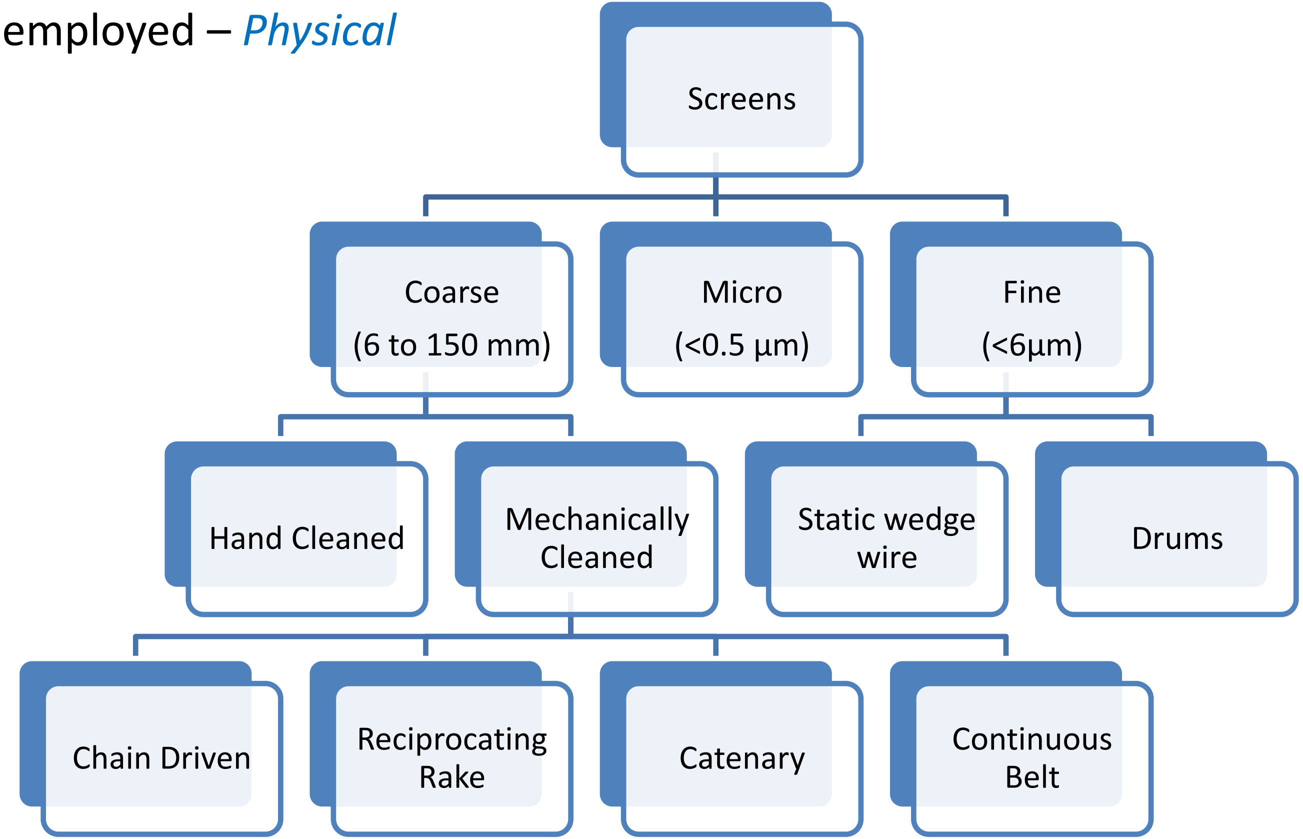
Treatment Methods employed – *Physical*

Screens (Screening)

- Screening is the device with openings, generally of uniform sizes that is used to retain solids found in the wastewater.
- Its primary role is to remove coarse materials from waste water that could (a) damage subsequent equipment in the treatment process and (b) reduce overall treatment process reliability and effectiveness.

Treatment Methods employed – *Physical*

Classification *of* Screens



Treatment Methods employed – *Physical*

Grit separators (or Grit Chambers)

- Removal of grit from wastewater may be accomplished by the grit chambers.
- Grit chambers are designed to remove grit consisting of sand, gravel or heavy solid materials.
- Grit chambers are mostly located after bar screens and before primary sedimentation tank.

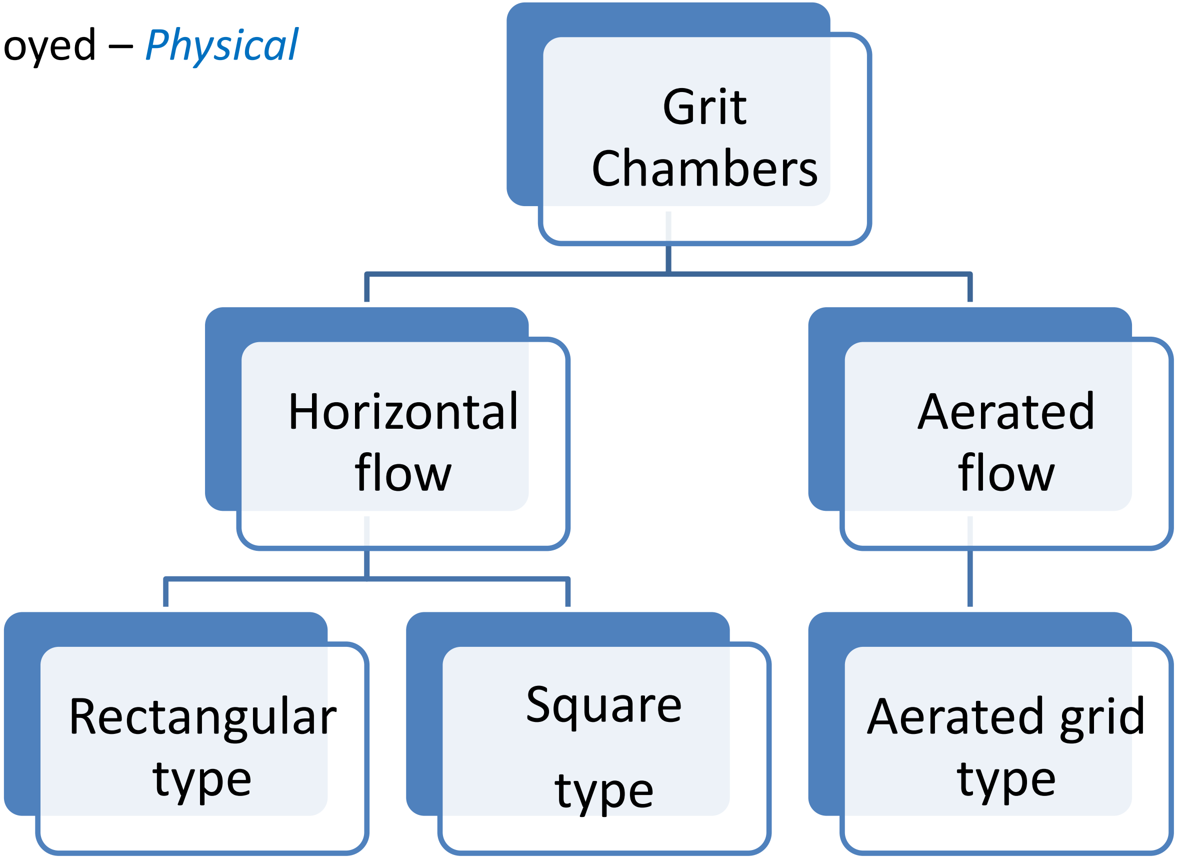
Treatment Methods employed – *Physical*

Grit separators (or Grit Chambers)

- Grid chambers are provided to (i) reduce the formation of heavy deposits in pipelines, channels and conduits; and (ii) reduces the frequency of digesters cleaning caused by excessive accumulation of grit.

Treatment Methods employed – *Physical*

Classification
of
Grit Chambers

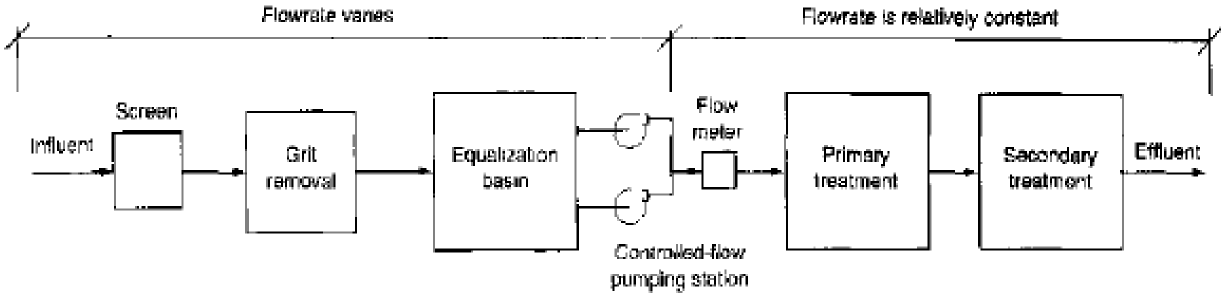


Treatment Methods employed – *Physical*

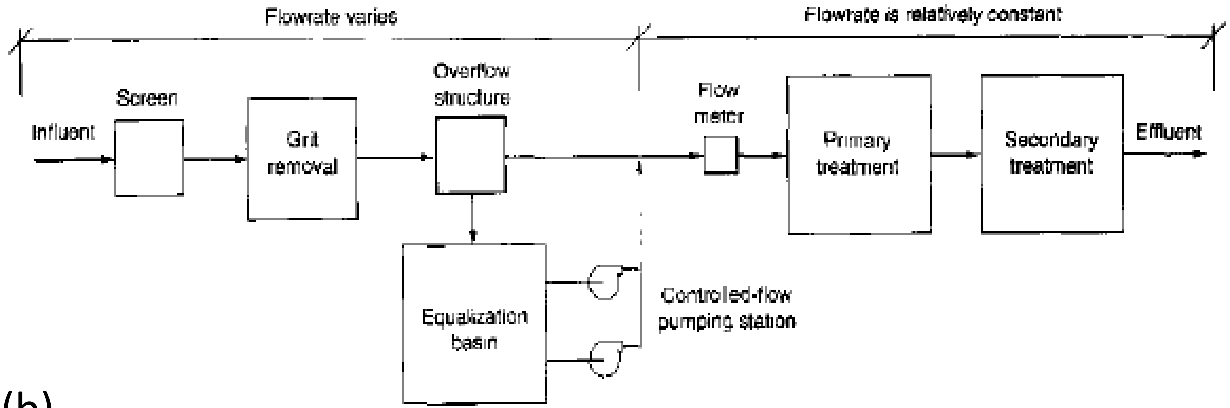
Flow equalizers

- Flow equalization is a method used to overcome the operational problems caused by flow rate variation to improve the performance of downstream processes and to reduce size and cost of subsequent downstream treatment facilities.

Levels of wastewater Treatment



(a)



(b)

Typical wastewater-treatment plant flow diagram incorporating flow equalization: (a) in-line equalization and (b) off-line equalization. Flow equalization can be applied after grit removal, after primary sedimentation, and after secondary treatment where advanced treatment is used.

Treatment Methods employed – *Physical*

Sedimentation

- The objective of sedimentation is to remove readily settleable solids and reduce the suspended solids.
- Sedimentation tanks are usually constructed of reinforced concrete and may be circular, square or rectangular in plain view.
- Circular tanks may be ranging from 15 to 300 ft (4.57 t0 91.43 m) in diameter and are usually from 6 to 16 ft (1.83 to 4.88 m) deep.

Treatment Methods employed – *Physical*

Sedimentation

- The types of settling involved in sedimentation tank are (a) Type – I (*Free settling*), (b) Type – II (*Flocculate during settling*), (C) Type – III (Zone or hindered settling), (d) Type – IV (*Compression settling*)

Treatment Methods employed – *Physical*

Sedimentation – (a) Type – I (Free or discrete settling)

- It is the free settling of discrete, non flocculent particles in dilute suspensions.
- The particles settles as separate units and then no apparent flocculation or interaction between the particles
- Hence the particles maintains individuality as it settles and does not interact with other settling particles, and therefore does not change in size, shape or density.

Treatment Methods employed – *Physical*

Sedimentation – (b) Type – II (Flocculate during settling)

- The settling of particles in dilute suspensions. The particles flocculate during settling; thus they increase the size and settle at a faster rate.

Treatment Methods employed – *Physical*

Sedimentation – (C) Type – III (Zone or hindered settling)

- The concentration of the particle in which they are so close together that inter particle force hinder the settling of neighbouring particles.
- The particles remain in a fixed position relative to each other and all settle at constant velocity.
- As a result the mass of the particle settles as a zone. At the top of the settling mass, there will be distinct solid-liquid interface between settling particle and clarified liquid.

Treatment Methods employed – *Physical*

Sedimentation – (C) Type – IV (Compression settling)

- The settling of particles that are at such concentration that the particle touch each other and settling can occur only by compression.

Treatment Methods employed – *Physical*

Sedimentation – Type – I (a) Type – I (Free settling)

- The types of settling involved in sedimentation tank are, (b) Type – II (Flocculate during settling), (C) Type – III (Zone or hindered settling), (d) Type – IV (Compression settling)

Treatment Methods employed – *Physical*

Clarifiers - Mixing, flocculation

- Flocculator clarifiers are often used in Industrial wastewater treatment, especially where enhanced settling is required
- Inorganic chemicals or polymers can be added to improve flocculation
- These clarifiers are equipped with a paddle-type or low-speed mixer
- The gentle stirring causes flocculent particles to form and the solids are settled down and scum are collected

Treatment Methods employed – *Physical*

Coagulation

- Many industrial wastewater contain suspended or colloidal waste materials that are too small to be effectively removed by gravity separation.
- Removal of colloidal particles becomes difficult by the fact that they usually have a surface electrical charge that causes them to repel other particles, thus preventing agglomeration to a size that could settle
- For these small suspended particles and colloids to be removed from suspension, the surface charge must be destabilized and the particle must brought together so that they can achieve a settlable size. This is the role of coagulation.

Treatment Methods employed – *Physical*

- Coagulation result from the addition and rapid mixing of a coagulant with the waste water to neutralize surface charges, collapse the surface layer around the particle, and allow the particle to come together and agglomerate
- The resulting formation, called a *floc*, can more readily settle
- A number of coagulants are in common use. The most popular coagulants are alum or aluminium sulfate and iron salts (ferric chloride, ferrous sulfate and ferric sulfate)

Treatment Methods employed – *Physical*

Flotation

- Flotation is essentially the *reverse of sedimentation*
- If the wastewater contains solids or immiscible liquids that are lighter than water, they will float to the surface in a flotation tank, where they can be skimmed off
- Materials that are heavier than water, such as light solids or grease, may also be removed by flotation if they are made more buoyant by the attachment of air bubbles to their surfaces

Treatment Methods employed – *Physical*

- In air flotation, air is bubbled into the bottom of the flotation tank or water containing pressurized air is injected into the bottom of the tank so that air bubbles are released from solution when the water pressure is reduced to that in the tank
- The rising air microbubbles intercept suspended solids in the water; attach themselves to the particles, making them more buoyant; and carry them to the surface, where they are skimmed off.

Treatment Methods employed – *Physical*

- Clarified liquid is removed from the bottom of the tank
- This process is particularly useful for material whose density is close to that of water
- A common use of flotation is in the separation of free oil from waters

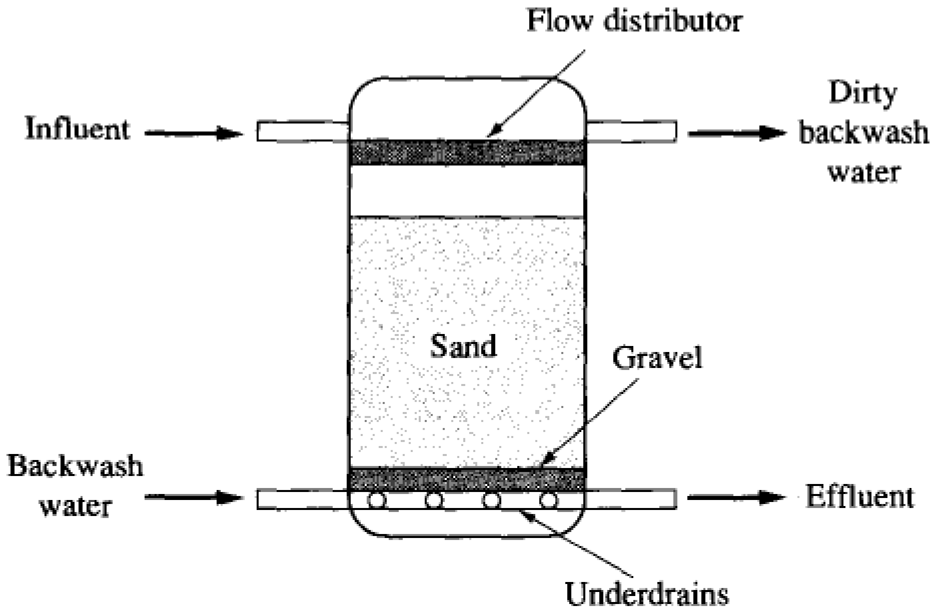
Treatment Methods employed – *Physical*

Filters – Sand Filtration

- Filters are often used after settling tanks to remove solids that did not settle.
- There are many processes that fall under the heading of filtration.
- Among these are screens, granular media filters, vacuum filters, filter presses, and various types of membrane filters
- Filtration processes can be used to remove suspended solids from industrial wastewaters, as a stand-alone process to remove larger particles, as a pre-treatment device before other treatment processes such as activated carbon adsorption or membrane units, or following chemical treatment

Treatment Methods employed – *Physical*

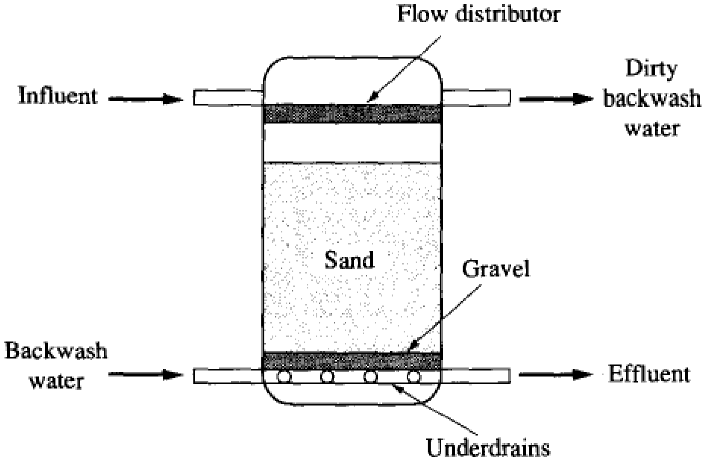
Filters – Sand Filtration



Treatment Methods employed – *Physical*

Filters – Sand Filtration

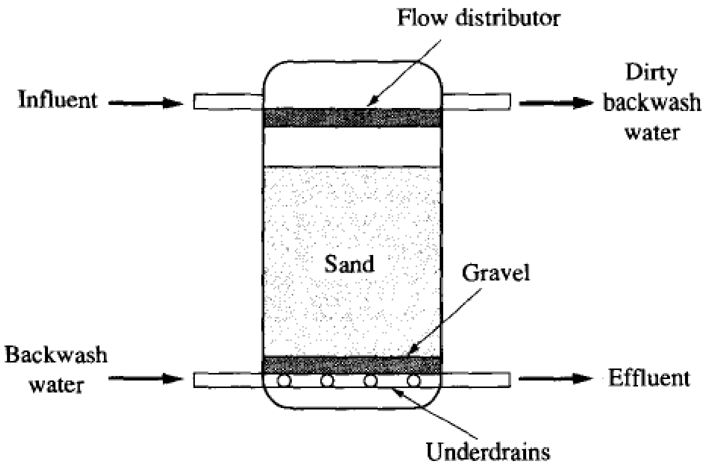
- Granular media filters consist of beds of granular media, such as sand, through which the wastewater passes.
- In industry, the filter medium is usually housed in a cylindrical vessel; gravity filters can be used but usually the liquid flows down through the medium due to an applied pressure (see Figure)



Treatment Methods employed – *Physical*

Filters – Sand Filtration

- The filter medium is supported by a bed of gravel to prevent short-circuiting and ensure uniform flow through the medium and out of the reactor.
- When build-up of accumulated solids causes pressure losses through the medium to become excessive, flow to the filter is stopped and the filter medium is backwashed by forcing water up through the medium.

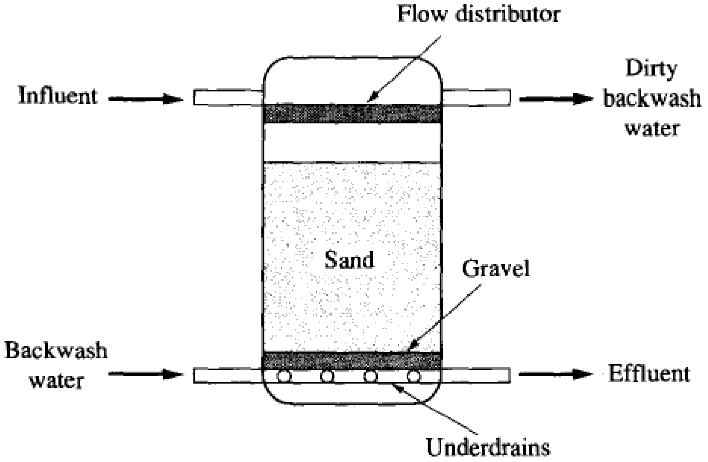


Treatment Methods employed – *Physical*

Filters – Sand Filtration

- The medium expands due to the buoyant forces from the rising water, contaminants become dislodged, and they flow out of the filter to waste.

- When the backwash water is turned off, the fluidized filter medium settles back to the gravel base in a size-segregated fashion with the larger, heavier granules on the bottom and the lighter materials on top.

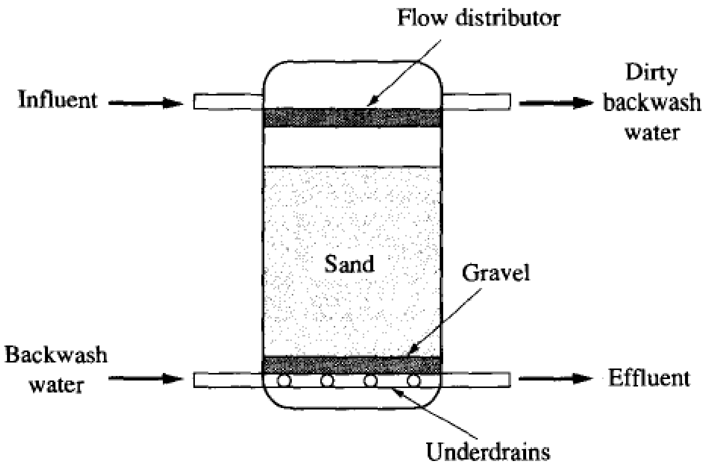


Treatment Methods employed – *Physical*

Filters – Sand Filtration

- Granular media filters remove particles on the surface of the filter by straining and throughout the filter depth by a combination of straining, particle adsorption to the filter media's surfaces, and flocculation and settling within the pores between granules.

- As suspended solids are removed from the passing water, the bed's porosity and permeability decrease, increasing removal efficiency but also increasing head losses.



Treatment Methods employed – *Physical*

Membrane separations

- Membrane separation of solids from an industrial wastewater is actually a subset of filtration.
- It can be used to separate colloidal and dissolved solids that are much smaller than those removed by other filtration processes.
- The membranes used have pores sufficiently small that even small molecules or ions can be removed.

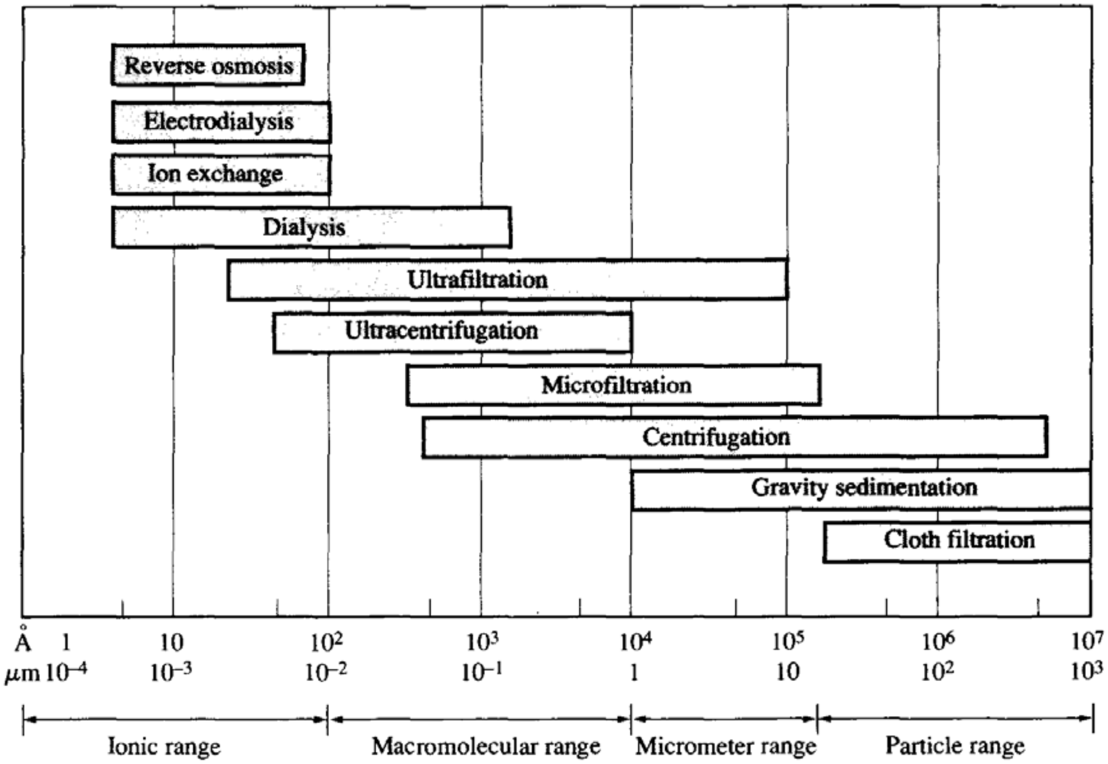
Treatment Methods employed – *Physical*

Membrane separations

- The membranes can be made selectively permeable for specific materials so that separations of these materials can be achieved.
- Membrane processes are very effective, but the rate of transfer across the membrane is generally slow and pressure drops are high; large membrane areas are generally required.
- Membrane filtration includes a broad range of separation processes: ultrafiltration, dialysis, electro-dialysis, reverse osmosis, and so on.

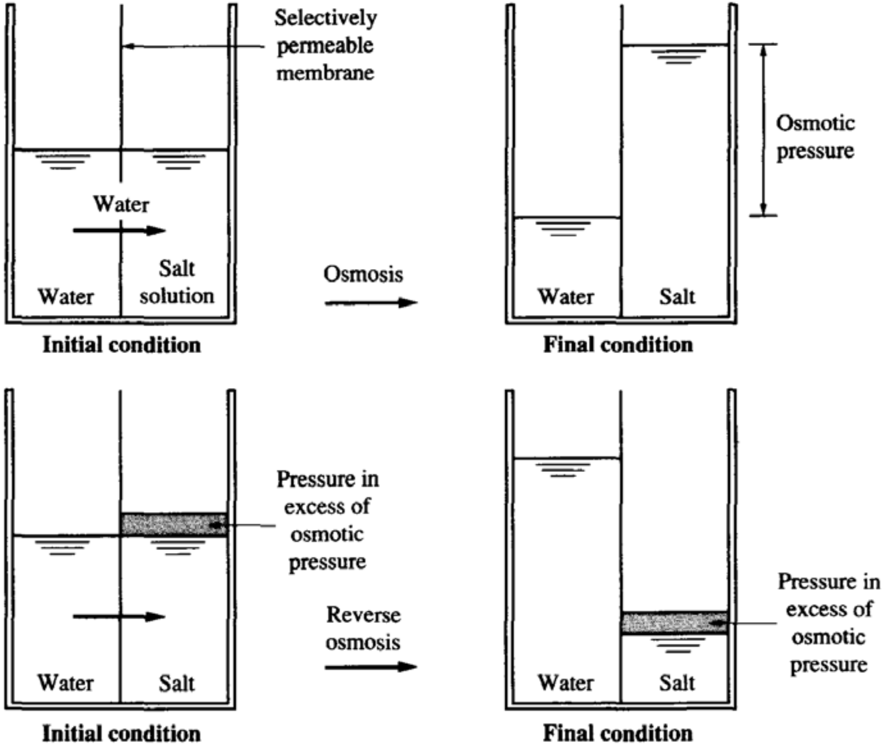
Treatment Methods employed – *Physical*

Effective range of various filtration and membrane processes



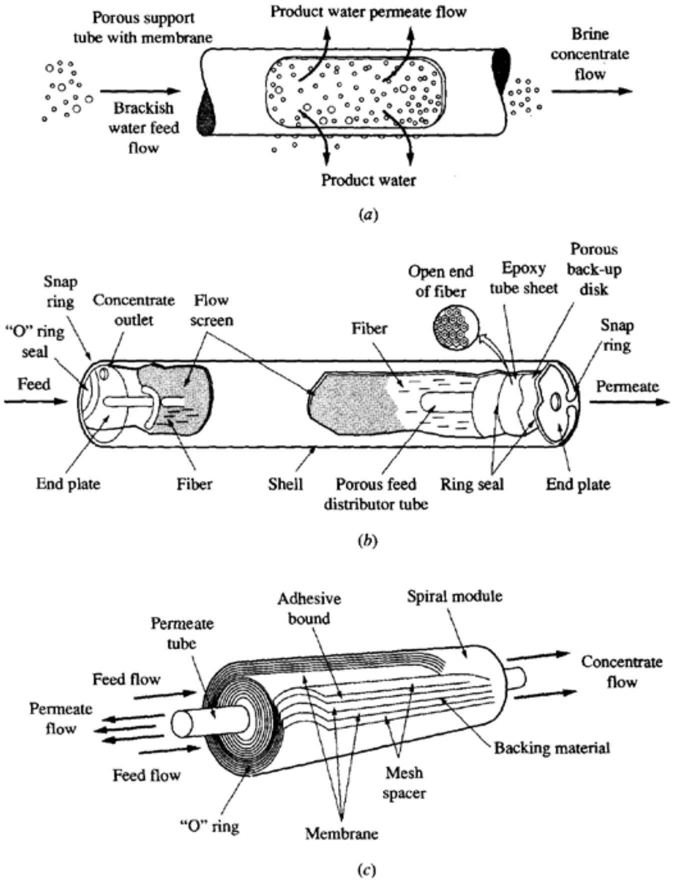
Treatment Methods employed – *Physical*

Schematic representation of osmotic and reverse osmosis mechanisms



Treatment Methods employed – *Physical*

Schematic representation of three types of reverse osmosis membrane systems (a) tubular membrane (b) hollow fibre membrane (c) spiral wound membrane



Treatment Methods employed – *Physical*

Adsorption

- Adsorption consists of transferring the contaminant from the aqueous waste phase to the surfaces of an adsorbent material.
- The most commonly used adsorbent is activated carbon because of its large surface area, ability to sorb a wide variety of compounds, and its low cost relative to other comparable adsorbents.
- In essence, adsorption occurs primarily due to van der Waals' forces, molecular forces of attraction between the solute and the solvent (physical adsorption).

Treatment Methods employed – *Physical*

Adsorption

- When the forces of attraction between the solute and the sorbent are greater than those between the solute and water, the solute will come out of solution and attach itself to the sorbent surface.
- Some adsorption also occurs because of chemical reactions between the solute and active groups on the activated carbon pore surface (chemical adsorption), but this is usually minor in comparison to physical adsorption. Chemical adsorption is usually irreversible.

Treatment Methods employed – *Chemical*

Ion Exchange

- Ion exchange is a chemical treatment process used to remove unwanted ionic species from wastewater.
- In industrial wastewater treatment, it is predominantly used to remove cations (i.e., heavy metals) from solution, but it can also be used to remove anions such as cyanide, arsenates, and chromate.
- As the name implies, ion exchange works by exchanging undesirable cations or anions in solution with less harmful ones from an ion exchange resin.

Treatment Methods employed – *Chemical*

Ion Exchange

- Thus the harmful ions are removed from the aqueous stream and attached to the resin.
- The ions are not destroyed but rather are removed from the waste stream and concentrated on the resin, where they can be more easily handled.
- The exchange reaction is reversible, and the exchanged contaminants can later be removed from the resin, making the resin available for reuse.

Treatment Methods employed – *Chemical*

Ion Exchange

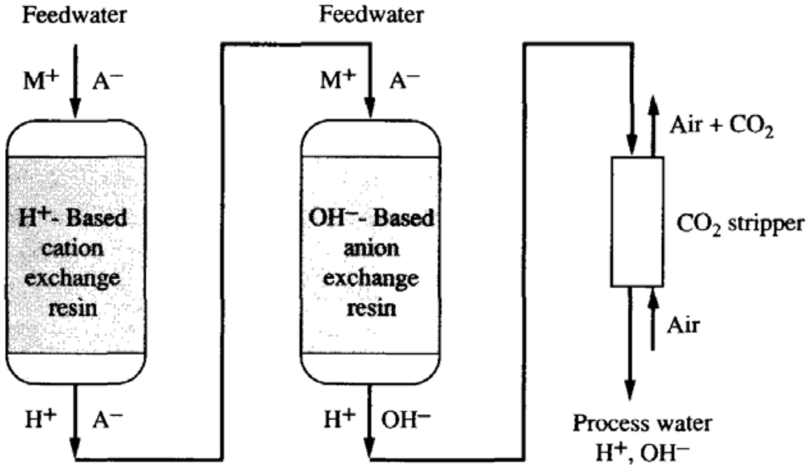
- Ion exchange resins consist of inorganic minerals with a deficit of positive atoms within the crystalline structure, known as *zeolites,* or synthetic organic polymeric materials that have ionizable functional groups, such as sulfonic, phenolic, carboxylic, amine, or quaternary ammonium.

- Zeolites are essentially all cation exchange materials (they exchange positively charged ions); the negatively charged zeolite surface is counterbalanced by exchangeable cations in solution next to the negative sites.

Treatment Methods employed – *Chemical*

Ion Exchange

- These loosely held cations can be readily replaced by higher valence state cations (i.e., heavy metals) in the wastewater.



Schematic representation of Demineralization of water by ion exchange

Treatment Methods employed – *Chemical*

Precipitation (Chemical oxidation and reduction)

- Chemical oxidation or reduction (redox) systems are used to treat several industrial wastewater types.
- Recent research on *advanced oxidation processes* (AOPs) has been promising and may soon allow oxidation processes to be used on a wider scale.
- Chemical oxidation is a process in which one or more electrons are transferred from the chemical being oxidized to the chemical initiating the transfer (the oxidizing agent).

Treatment Methods employed – *Chemical*

Precipitation (Chemical oxidation and reduction)

- Thus *oxidation* of a substance results in the loss of electrons from the substance, whereas *reduction* of a substance results in a gain of electrons in the substance.
- Oxidation and reduction reactions must be coupled together because free electrons cannot exist in solution.
- In the case of industrial waste treatment, pollutants are oxidized or reduced to products that are less toxic, more readily biodegradable, or more readily removed by adsorption.

Precipitation (Chemical oxidation and reduction)

- There are a number of chemical oxidizing and reducing agents and several commonly accepted treatment systems that they can be applied to. Among the more common oxidizing agents are *ozone, hydrogen peroxide, chlorine, and potassium permanganate.*
- These are currently used to oxidize cyanides, sulfides, phenols, pesticides, and some other organic compounds. Typical reducing agents are ferrous sulfate, sodium metabisulfite, sodium borohydride, and sulfur dioxide.
- They are predominantly used to reduce a metal, particularly chromium, to its less soluble and less toxic trivalent state.

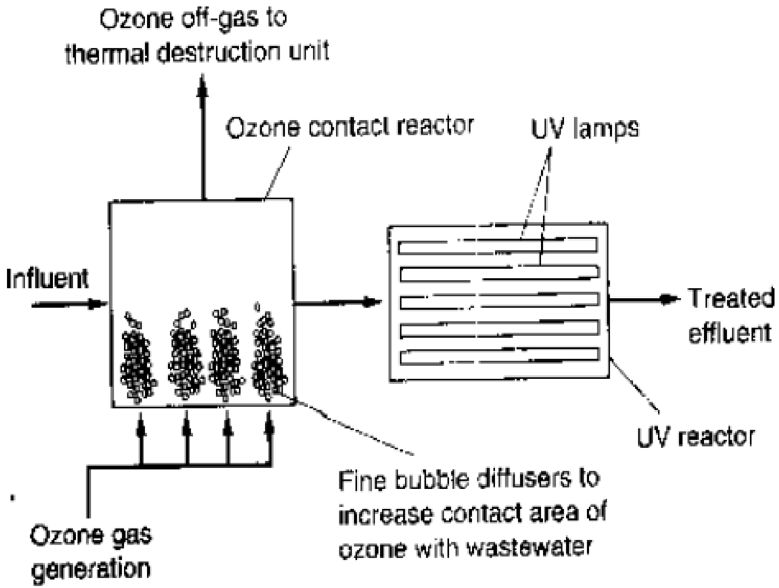
Treatment Methods employed – *Chemical*

Precipitation (Chemical oxidation and reduction) for the removal of chfomium

Schematic of the chromium reduction and precipitation

Treatment Methods employed – *Chemical*

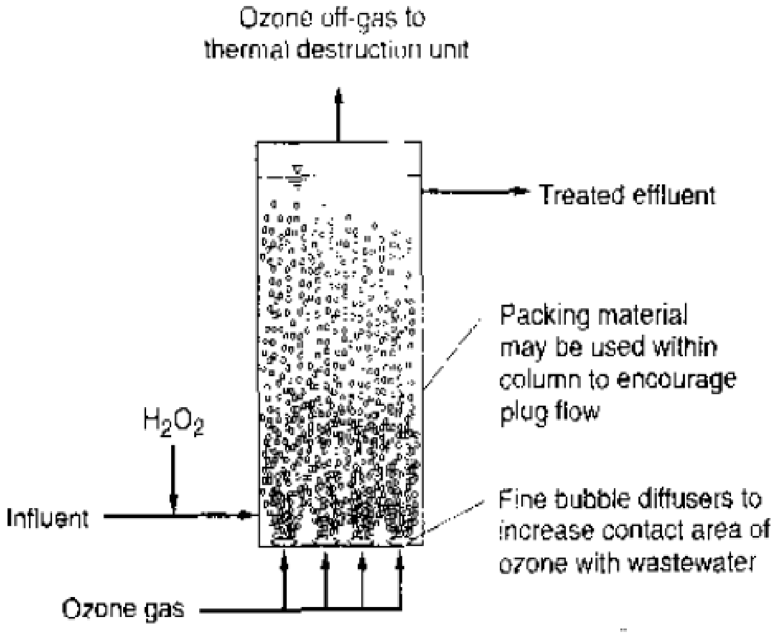
Precipitation (Chemical oxidation and reduction) for the removal of chfomium



Schematic of the ozone oxidation and UV radiation

Treatment Methods employed – *Chemical*

Precipitation (Chemical oxidation and reduction) for the removal of chfomium



Schematic of the advanced oxidation process involving the use of ozone and hydrogen peroxide (H_2O_2)

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