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Physico-Chemical Waste Water Treatment Technologies: An Overview

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ABSTRACT:

Waste-water treatment is becoming even more important in the light of diminishing water resources, increasing industrial, domestic and agriculture water usage and consequently waste-water disposal and its costs along with stricter discharge regulations that have lowered permissible contaminant levels in waste streams. The treatment of waste-water for reuse and disposal is particularly important for water scarce states like Rajasthan, Maharashtra, and other states in India where water availability is highly critical. The municipal sector consumes significant volumes of water, and consequently generates considerable amounts of waste-water discharge. Municipal waste-water is a combination of water and water-carried wastes originating from homes, commercial and industrial facilities, and institutions. The present paper comprises of the various Physico-Chemical methods and technologies currently used in waste-water treatment, with emphasis on municipal waste-water.

Keywords: *Waste Water, Physico-Chemical Treatment, Unit Processes and Operations of Treatment Systems.*

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INTRODUCTION:

Municipal waste-water is the combination of liquid or water-carried wastes originating in the sanitary Conveniences of dwellings, commercial or industrial facilities and institutions. Untreated waste-water generally contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds. It thus entails environmental and health hazards, and, Consequently, must immediately be conveyed away from its generation sources and treated appropriately before final disposal. The ultimate goal of waste-water management is the protection of the environment in a manner commensurate with public health and socio-economic concerns.1

Waste-water treatment in the present paper focusses on various waste-water treatment technologies, technical details on treatment methods, applications and sludge disposal. It also discuss the management of treated effluents and how they are reused and disposed of.

WASTE-WATER TREATMENT TECHNOLOGIES:

Waste Water Treatment primarily consists of Physical, Chemical and Biological methods used to remove contaminants from waste-water. In order to achieve different levels of contaminant removal, individual waste-water treatment procedures are combined into a variety of systems, classified as primary, secondary, and tertiary waste-water treatment. More rigorous treatment of waste-water includes the removal of specific contaminants as well as the removal and control of nutrients. Natural systems are also used for the treatment of waste-water in land-based applications. Sludge resulting from waste-water treatment operations is treated by various methods in order to reduce its water and organic content and make it suitable for final disposal and reuse. This paper describes the various conventional and advanced technologies in current use and explains how they are applied for the effective treatment of municipal waste-water.

WASTE-WATER TREATMENT METHODS:

Waste-water treatment methods are broadly classifiable into physical, chemical and biological processes. Table – 1 below lists the unit operations included within each category

Table-1: Waste-water treatment unit operations and processes

Physical unit operations	☐ Screening ☐ Comminution ☐ Flow equalization ☐ Sedimentation ☐ Flotation ☐ Granular-medium filtration
Chemical unit operations	☐ Chemical precipitation ☐ Adsorption ☐ Disinfection ☐ DE chlorination ☐ Other chemical applications
Biological unit operations	☐ Activated sludge process ☐ Aerated lagoon ☐ Trickling filters ☐ Rotating biological contactors ☐ Pond stabilization ☐ Anaerobic digestion ☐ Biological nutrient removal

1. PHYSICAL UNIT OPERATIONS:

Among the first treatment methods used are physical unit operations, in which physical forces are applied to remove contaminants. They still form the basis of most process flow systems for wastewater treatment. The most commonly used physical unit operations are.

(a) Screening:

The screening of waste-water, one of the oldest treatment methods, removes gross pollutants from the Waste stream to protect downstream equipment from damage, avoid interference with plant operations and prevent objectionable floating material from entering the primary settling tanks. Screening devices may consist of parallel bars, rods or wires, grating, wire mesh, or perforated plates, to intercept large floating or Suspended material. The openings may be of any shape, but are generally circular or rectangular. The material retained from the manual or mechanical cleaning of bar racks and screens is referred to as “Screenings”, and is either disposed of by burial or incineration, or returned into the waste flow after grinding. The principal types of screening devices are listed in table 2.

Table 2: Screen Types

Screen category	Size of openings (millimeters)	Application	Types of screens
Coarse screens	≥ 6	Remove large solids, rags, and debris.	☐ Manually cleaned bar screens/trash racks ☐ Mechanically cleaned bar screens/trash racks o Chain or cable driven with front or back

			cleaning o Reciprocating rake screens o Catenary screens o Continuous self-cleaning screens
Fine screens	1.5-6	Reduce suspended solids to primary treatment levels	□ Rotary-drum screens □ Rotary-drum screens with outward or inward flow □ Rotary-vertical-disk screens □ Inclined revolving disc screens □ Traveling water screens □ Endless band screen □ Vibrating screens
Very fine screens	0.2-1.5	Reduce suspended solids to primary treatment levels	
Micro screens	0.001-0.3	Upgrade secondary effluent to tertiary standards	

The coarse screen category includes manually or mechanically cleaned bar screens and trash racks. Bar screens consist of vertical or inclined steel bars distributed equally across a channel through which waste-water flows. They are used ahead of mechanical equipment including raw sewage pumps, grit chambers, and primary sedimentation tanks. Trash racks, are constructed of parallel rectangular or round steel bars with clear openings. They are usually followed by regular bar screens or comminutors. Criteria used in the design of coarse screens include bar size, spacing, and angle from the vertical, as well as channel width and waste-water approach velocity. Fine screens consist of various types of screen media, including slotted perforated plates, wire mesh, woven wire cloth and wedge-shaped wire. Due to their tiny openings, fine screens must be cleaned continuously by means of brushes, scrapers, or jets of water, steam, or air forced through the reverse side of the openings. The efficiency of a fine screen depends on the fineness of the openings as well as the sewage flow velocity through those openings.

(b) Comminution:

Comminutors are used to pulverize large floating material in the waste flow. They are installed where the handling of screenings would be impractical, generally between the grit chamber and the primary settling tanks. Their use reduces odors, flies and unsightliness. A comminutor may have either rotating or oscillating cutters. Rotating-cutter comminutors either engage a separate stationary screen alongside the cutters, or a combined screen and cutter rotating together. A different type of comminutor, known as a barminutor, involves a combination of a bar screen and rotating cutters.

(c) Flow equalization:

Flow equalization is a technique used to improve the effectiveness of secondary and advanced wastewater treatment processes by levelling out operation parameters such as flow, pollutant levels and temperature over a period of time. Variations are damped until a near-constant flow rate is achieved, minimizing the downstream effects of these parameters. Flow equalization may be applied at a number of locations within a waste-water treatment plant, e.g. near the head end of the treatment works, prior to discharge into a water body, and prior to advanced waste treatment operations. There are four basic flow equalization processes that are summarized in table 3.

Table 3. Basic Flow Equalization Processes:

Process	Description	Illustration
Alternating flow diversion	Two basins alternating between filling and discharging for successive time periods	Influent Equalization basin Equalization basin Treatment facility Effluent
Intermittent flow diversion	An equalization basin to which a significant increase in flow is diverted. The diverted flow is then fed into the system at a controlled rate	Influent Equalization basin Treatment facility Effluent
Completely mixed, combined flow	A basin that completely mixes multiple flows at the front end of the treatment process	Flow 1 Flow 2 Flow 3 Mixed basin Treatment facility Effluent
Completely mixed, mixed flow	A large, completely mixed, holding basin located before the waste-water facility, levelling parameters in influent stream and providing a constant discharge	Influent Equalization basin Treatment facility Effluent

(d) Sedimentation:

Sedimentation, a fundamental and widely used unit operation in waste-water treatment, involves the gravitational settling of heavy particles suspended in a mixture. This process is used for the removal of grit, particulate matter in the primary settling basin, biological floc in the activated sludge settling basin, and chemical flow when the chemical coagulation process is used. Sedimentation takes place in a settling tank, also referred to as a clarifier. There are three main designs, namely, horizontal flow, solids contact and inclined surface. In designing a sedimentation basin, it is important to bear in mind that the system must produce both a clarified effluent and a concentrated sludge. Four types of settling occur, depending on particle concentration, namely,, discrete, flocculent, hindered and compression. It is common for more than one type of settling to occur during a sedimentation operation.

(i) Horizontal flow:

Horizontal-flow clarifiers may be rectangular, square or circular in shape (see figure 1). The flow in rectangular basins is rectilinear and parallel to the long axis of the basin, whereas in Centre-feed circular basins, the water flows radially from the Centre towards the outer edges. Both types of basins are designed to keep the velocity and flow distributions as uniform as possible in order to prevent currents and eddies from forming, and thereby keep the suspended material from settling. Basins are usually made of steel or reinforced concrete. The bottom surface slopes slightly to facilitate sludge removal. In rectangular tanks, the slope is towards the inlet end, while in circular and square tanks, the bottom is conical and slopes towards the Centre of the basin.

(ii) Solid contact clarifiers:

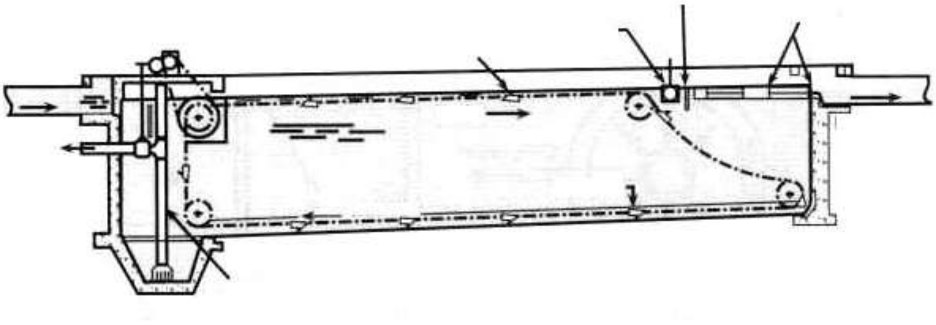
Solid contact clarifiers bring incoming solids into contact with a suspended layer of sludge near the bottom that acts as a blanket. The incoming solids agglomerate and remain enmeshed within the sludge blanket, whereby the liquid is able to rise upwards while the solids are retained below.

iii) Inclined surface basins:

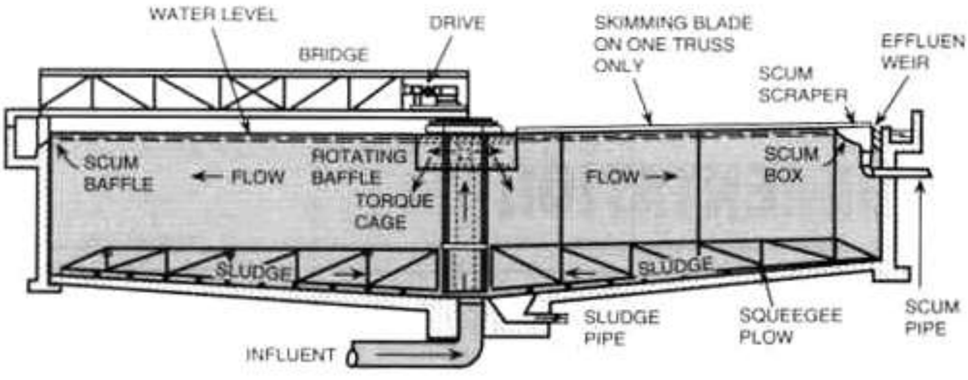
Inclined surface basins, also known as high-rate settlers, use inclined trays to divide the depth into shallower sections, thus reducing particle settling times. They also provide a larger surface area, so that a smaller-sized clarifier can be used. Many overloaded horizontal flow clarifiers have been upgraded to inclined surface basins. Here, the flow is laminar, and there is no wind effect.

Figure 1. Settling basin with horizontal flow:

(a) Parts of a rectangular basin:



(b) Parts of circular tank:



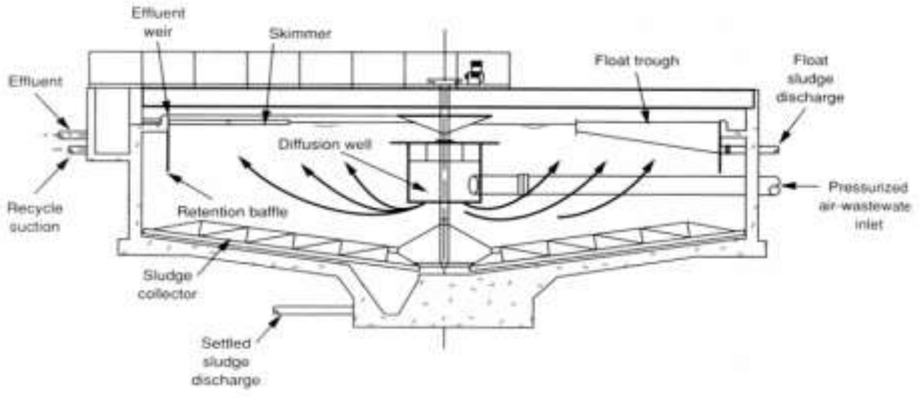
(e) Flotation:

Flotation is a unit operation used to remove solid or liquid particles from a liquid phase by introducing a fine gas, usually air bubbles. The gas bubbles either adhere to the liquid or are trapped in the particle structure of the suspended solids, raising the buoyant force of the combined particle and gas bubbles. Particles that have a higher density than the liquid can thus be made to rise. In waste-water treatment, flotation is used mainly to remove suspended matter and to concentrate biological sludge. The chief advantage of flotation over sedimentation is that very small or light particles can be removed more completely and in a shorter time. Once the particles have been floated to the surface, they can be skimmed out. Flotation, as currently practiced in municipal waste-water treatment, uses air exclusively as the floating agent. Furthermore, various chemical additives can be introduced to enhance the removal process. The various flotation methods are described in table 4, while a typical flotation unit is illustrated in figure 2.

Table 4. Flotation Methods:

Process	Description
Dissolved-air flotation	The injection of air while waste-water is under the pressure of several atmospheres. After a short holding time, the pressure is restored to atmospheric level, allowing the air to be released as minute bubbles
Air flotation	The introduction of gas into the liquid phase directly by means of a revolving impeller or through diffusers, at atmospheric pressure
Vacuum flotation	The saturation of waste-water with air either directly in an aeration tank or by permitting air to enter on the suction side of a waste-water pump. A partial vacuum is applied, causing the dissolved air to come out of solution as minute bubbles which rise with the attached solids to the surface, where they form a scum blanket. The scum is removed by a skimming mechanism while the settled grit is raked to a central sump for removal
Chemical additives	Chemicals further the flotation process by creating a surface that can easily adsorb or entrap air bubbles. Inorganic chemicals (aluminum and ferric salts and activated silica) and various organic polymers can be used for this purpose

Figure 2. Typical flotation unit



(f) Granular medium filtration:

The filtration of effluents from waste-water treatment processes involves removal of suspended solids from waste-water effluents of biological and chemical treatment processes, in addition to the removal of chemically precipitated phosphorus. The complete filtration operation comprises two phases: filtration and cleaning or backwashing. The waste-water to be filtered is passed through a filter bed consisting of granular material (sand, anthracite and/or garnet), with or without added chemicals. Within the filter bed, suspended solids contained in the waste-water are removed by means of a complex process involving one or more removal mechanisms such as straining, interception, impaction, sedimentation, flocculation and adsorption. The Cleaning/backwashing phase differs, depending on whether the filter operation is continuous or semi continuous. In semi-continuous filtration, the filtering and cleaning operations occur sequentially, whereas in continuous filtration the filtering and cleaning operations occur simultaneously.

2. CHEMICAL UNIT PROCESSES:

Chemical processes used in waste-water treatment are designed to bring about some form of change by means of chemical reactions. They are always used in conjunction with physical unit operations and biological processes. In general, chemical unit processes have an inherent disadvantage compared to physical operations in that they are additive processes. That is to say, there is usually a net increase in the dissolved constituents of the waste-water. This can be a significant factor if the waste-water is to be reused. The present paper discusses the main chemical unit processes, including chemical precipitation, adsorption, disinfection, chlorination and other applications.

(a) Chemical precipitation:

Chemical coagulation of raw waste-water before sedimentation promotes the flocculation of finely divided solids into more readily settleable flocs, thereby enhancing the efficiency of suspended solid, BOD5 and phosphorus removal as compared to plain sedimentation without coagulation (see table 5). The degree of clarification obtained depends on the quantity of chemicals used and the care with which the process is controlled.

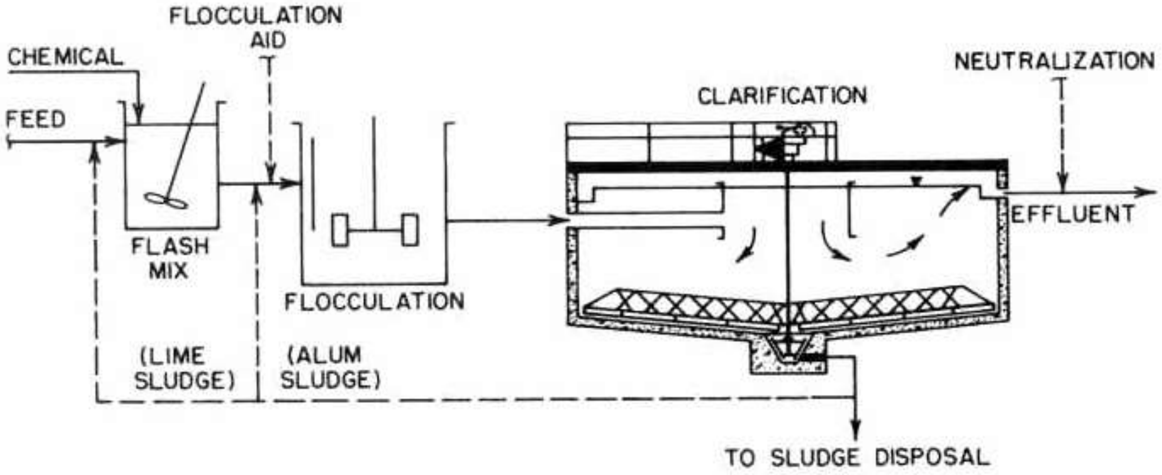
Table 5. Removal Efficiency Of Plain Sedimentation Vs. Chemical Precipitation:

Parameter	Percentage removal	
	Plain sedimentation	Chemical precipitation
Total suspended solids (TSS)	40-90	60-90
BOD5	25-40	40-70
COD		30-60
Phosphorus	5-10	70-90
Bacteria loadings	50-60	80-90

Coagulant selection for enhanced sedimentation is based on performance, reliability and cost.

Performance evaluation uses jar tests of the actual waste-water to determine dosages and effectiveness. Chemical coagulants that are commonly used in waste-water treatment include alum ($Al_2 (SO_4)_3.14.3\ H_2O$) Ferric chloride ($FeCl_3.6H_2O$), ferric sulfate ($Fe_2 (SO_4)_3$), ferrous sulfate ($FeSO_4.7H_2O$) and lime ($Ca (OH)_2$). Organic polyelectrolytes are sometimes used as flocculation aids. Suspended solids removal through chemical treatment involves a series of three unit operations: rapid mixing, flocculation and settling. First, the chemical is added and completely dispersed throughout the waste-water by rapid mixing for 20-30 seconds in a basin with a turbine mixer. Coagulated particles are then brought together via flocculation by mechanically inducing velocity gradients within the liquid. Flocculation takes 15 to 30 minutes in a basin containing turbine or paddle-type mixers. The final step is clarification by gravity. A once-through chemical treatment system is illustrated in figure 3.

Figure 3. A once-through chemical treatment system



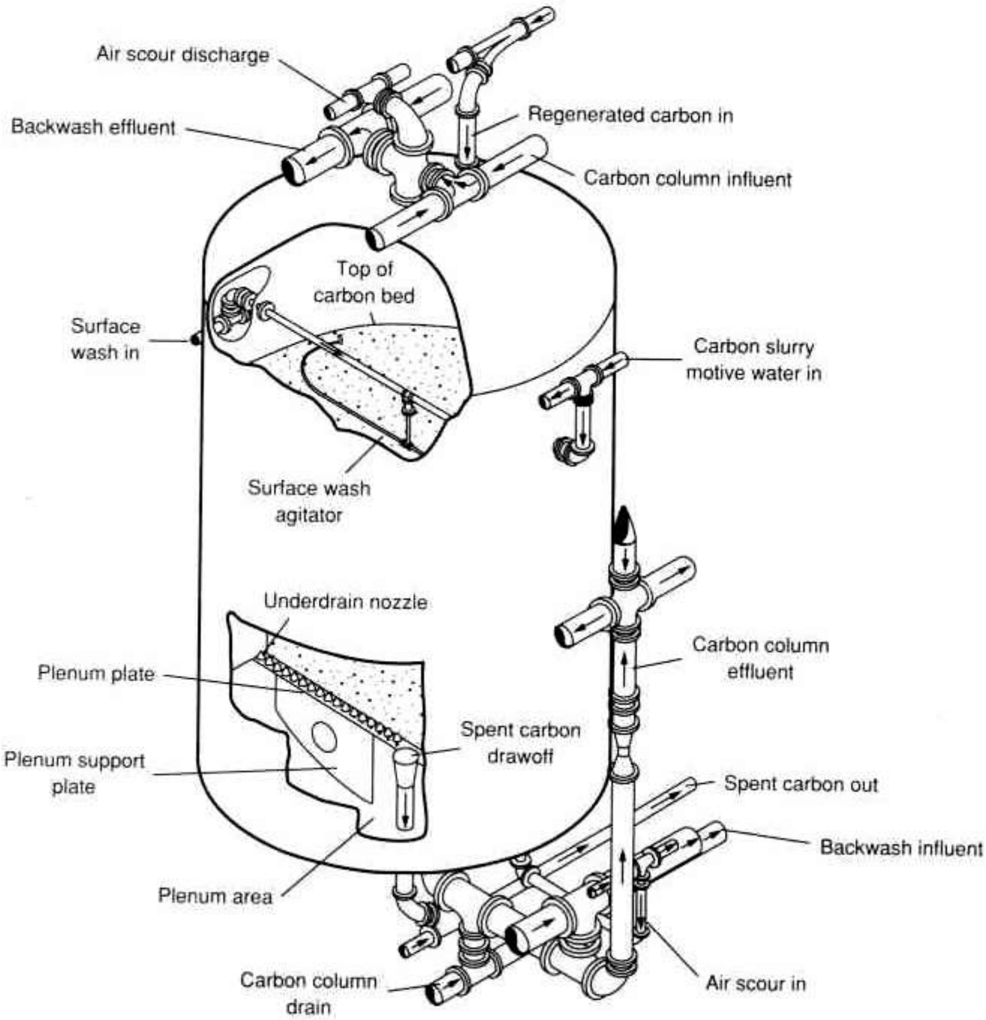
The advantages of coagulation include greater removal efficiency, the feasibility of using higher Overflow rates, and more consistent performance. On the other hand, coagulation results in a larger mass of primary sludge that is often more difficult to thicken and dewater. It also entails higher operational costs and demands greater attention on the part of the operator.

(b) Adsorption with activated carbon:

Adsorption is the process of collecting soluble substances within a solution on a suitable interface. In Waste-water treatment, adsorption with activated carbon—a solid interface—usually follows normal Biological treatment, and is aimed at removing a portion of the remaining dissolved organic matter. Particulate matter present in the water may also be removed. Activated carbon is produced by heating char to a high temperature and then activating it by exposure to an oxidizing gas at high temperature. The gas develops a porous structure in the char and thus creates a large internal surface area. The activated char can then be separated into various sizes with different adsorption capacities. The two most common types of activated carbon are granular activated carbon (GAC), which has a diameter greater than 0.1 mm, and powdered activated carbon (PAC), which has a diameter of less than 200 mesh. A fixed-bed column is often used to bring the waste-water into contact with GAC. The water is applied to the top of the column and withdrawn from the bottom, while the carbon is held in place.

Backwashing and surface washing are applied to limit head loss build-up. A schematic of an activated carbon Contactor is shown in figure 4. Expanded-bed and moving-bed carbon contactors have been developed to overcome the problem of head loss build-up. In the expanded-bed system, the influent is introduced at the bottom of the column and is allowed to expand. In the moving-bed system, spent carbon is continuously replaced with fresh carbon. Spent granular carbon can be regenerated by removal of the adsorbed organic matter from its surface through oxidation in a furnace. The capacity of the regenerated carbon is slightly less than that of the virgin carbon.

Figure 4. A typical granular activated carbon contactor:



Waste-water treatment using PAC involves the addition of the powder directly to the biological treatment effluent or the physiochemical treatment process, as the case may be. PAC is usually added to Waste-water in a contacting basin for a certain length of time. It is then allowed to settle to the bottom of the tank and removed. Removal of the powdered carbon may be facilitated by the addition of polyelectrolyte coagulants or filtration through granular-medium filters. A major problem with the use of powdered activated carbon is that the methodology for its regeneration is not well defined

(c) Disinfection:

Disinfection refers to the selective destruction of disease-causing micro-organisms. This process is of importance in waste-water treatment owing to the nature of waste-water, which harbours a number of human enteric organisms that are associated with various waterborne diseases. Commonly used means of disinfection include the following:

(i) Physical agents such as heat and light;

(ii) Mechanical means such as screening, sedimentation, filtration, and so on;

(iii) Radiation, mainly gamma rays;

(iv) Chemical agents including chlorine and its compounds, bromine, iodine, ozone, phenol and Phenolic compounds, alcohols, heavy metals, dyes, soaps and synthetic detergents, quaternary Ammonium compounds, hydrogen peroxide, and various alkalis and acids. The most common chemical disinfectants are the oxidizing chemicals, and of these, chlorine is the most widely used.

Table 6. Characteristics Of Common Disinfecting Agents:

Characteristic	Chlorine	Sodium hypochlorite	Calcium hypochlorite	Chlorine dioxide	Bromine chloride	Ozone	Ultraviolet light
Chemical formula	$Cl2$	NaOCl	$Ca(OCl)2$	$ClO2$	BrCl	$O3$	N/A
Toxicity to microorganisms	High	High	High	High	High	High	High
Solubility	Slight	High	High	High	Slight	High	N/A
Stability	Stable	Slightly unstable	Relatively stable	Unstable, must be generated as used	Slightly unstable	Unstable, must be generated as used	Must be Generated as used
Toxicity to higher forms of life	Highly toxic	Toxic	Toxic	Toxic	Toxic	Toxic	Toxic
Effect at ambient temperature	High	High	High	High	High	High	High
Penetration	High	High	High	High	High	High	Moderate
Corrosiveness	Highly corrosive	Corrosive	Corrosive	Highly corrosive	Corrosive	Highly corrosive	N/A
Deodorizing ability	High	Moderate	Moderate	High	Moderate	High	None
Availability/cost	Low cost	Moderately low cost	Moderately low cost	Moderately low cost	Moderately low cost	Moderately high cost	Moderately high cost
Form	Liquid, gas	Solution	Powder, pellets or 1 per cent solution	Gas	Liquid	Gas	UV energy

Disinfectants act through one or more of a number of mechanisms, including damaging the cell wall, altering cell permeability, altering the colloidal nature of the protoplasm and inhibiting enzyme activity. In applying disinfecting agents, several factors need to be considered: contact time, concentration and type of chemical agent, intensity and nature of physical agent, temperature, number of organisms, and nature of suspending liquid. Table 6 shows the most commonly used disinfectants and their effectiveness

(d) Dechlorination:

Dechlorination is the removal of free and total combined chlorine residue from chlorinated wastewater effluent before its reuse or discharge to receiving waters. Chlorine compounds react with many organic compounds in the effluent to produce undesired toxic compounds that cause long-term adverse impacts on the water environment and potentially toxic effects on aquatic micro-organisms. Dechlorination may be brought about by the use of activated carbon, or by the addition of a reducing agent such as sulfur dioxide

(SO_2), sodium sulfite (Na_2SO_3) or sodium metabisulfite ($Na_2S_2O_5$). It is important to note that dechlorination will not remove toxic by-products that have already been produced.

(e) Other chemical applications:

In addition to the chemical processes described above, various other applications are occasionally encountered in waste-water treatment and disposal. Table 7 lists the most common applications and the chemicals used

.

Table 7. Other Chemical Applications In Waste-Water Treatment And Disposal

Application	Chemical used	Remarks
Treatment		
Grease removal	Cl_2	Added before preaeration
BOD reduction	Cl_2, O_3	Oxidation of organic substances
pH control	KOH, NaOH, $Ca(OH)_2$	
Ferrous sulfate oxidation	Cl_2	Production of ferric sulfate and ferric chloride
Filter - ponding control	Cl_2	Residual at filter nozzles
Filter - fly control	Cl_2	Residual at filter nozzles, used during fly season
Sludge-bulking control	Cl_2, H_2O_2, O_3	Temporary control measure
Digester supernatant oxidation	Cl_2	
Digester and Imhoff tank foaming control	Cl_2	
Ammonia oxidation	Cl_2	Conversion of ammonia to nitrogen gas
Odour control	Cl_2, H_2O_2, O_3	
Oxidation of refractory organic compounds	O_3	
Disposal		
Bacterial reduction	Cl_2, H_2O_2, O_3	Plant effluent, overflows, and storm water
Odour control	Cl_2, H_2O_2, O_3	

CONCLUSIONS:

Physical and Chemical treatments are very important with in the waste water treatment systems and prior to any biological and advanced treatment technologies. Its understanding and conceptual knowledge is essential for any waste water treatment systems. In the present paper an attempt has been made to describe and illustrate the unit processes and operations of physical and chemical treatment in detail with a view to impart conceptual knowledge for the success of any waste water treatment technology

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