WATER TREATMENT PLANT – EQUIPMENTS & SIZING CALCULATIONS

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The objective of water treatment plant is to make water potable by removing the suspended matter and micro-organisms. Clarification is necessary step for removal of suspended solids and effective disinfection. Clarification usually involves-

- Coagulation
- Flocculation
- Settling / sedimentation
- Filtration

What We Remove in Clarification

Clarification helps in removal of suspended solids and colloids. Colloidal species encountered in raw water are-

- Clay
- Silica
- Iron & other heavy metals
- Color
- Organic solids such as debris of dead organisms
- Oil

The colloids can be categorized into hydrophilic and hydrophobic. Hydrophobic colloids do not react with water like most natural clays and hydrophilic colloids react with water like organics causing color. Hydrophilic colloids react with water treatment chemicals and hence require more chemical than hydrophobic colloid.

The key to effective coagulation and flocculation is an understanding of how individual colloids interact with each other. Turbidity particles range from about 0.01 to 100 microns in size. The larger fraction is relatively easy to settle or filter. The smaller, colloidal fraction, (from 0.01 to 5 microns), presents the real challenge. Their settling times are intolerably slow and they easily escape filtration. The behavior of colloids in water is strongly influenced by their electrokinetic charge. Each colloidal particle carries a like charge, which in nature is usually negative. This *like* charge causes adjacent particles to repel each other and prevents effective agglomeration and flocculation. As a result, charged colloids tend to remain discrete, dispersed, and in suspension.

Table 1: Settling time through 1 m water column

Particle Diameter			Type of Particle	Settling time through 1 m water column
mm	µm	Å		
10	10^{4}	10^{8}	Gravel	1 Second
1	10^{3}	10^{7}	Sand	10 Second
10^{-1}	10^{2}	10^{6}	Fine Sand	2 minutes
10^{-2}	10	10^{5}	Clay/Silt	2 hours
10^{-3}	1	10^{4}	Bacteria	8 days
10^{-4}	10^{-1}	10^{3}	Colloid	2 years
10^{-5}	10^{-2}	10^{2}	Colloid	20 years
10^{-6}	10^{-3}	10	Colloid	200 years

If the charge is significantly reduced or eliminated, then the colloids will gather together. First forming small groups, then larger aggregates and finally into visible floc particles which settle rapidly and filter easily.

What Makes Colloids Stable

The stability of colloids is best described by DLVO theory (named after Derjaguin, Landau, Verwery and Overbeek). The DLVO theory combines the van der Waals attraction curve and the electrostatic repulsion curve to explain the tendency of colloids to either remain discrete or to flocculate. The combined curve is called the *net interaction energy*. At each distance, the smaller energy is subtracted from the larger to get the net interaction energy. The net value is then plotted - above if repulsive, below if attractive – and the curve is formed.

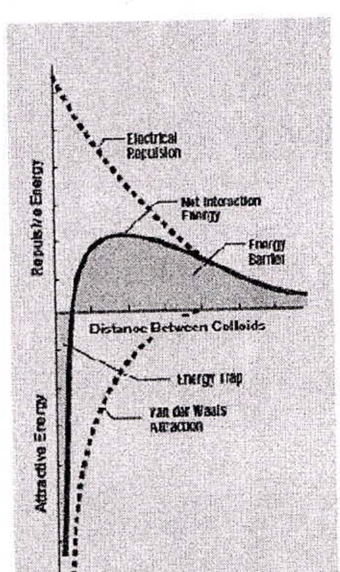

Figure 1: Net interaction energy curve

The net interaction curve can shift from attraction to repulsion and back to attraction with increasing distance between particles. If there is a repulsive section, then this region is called the *energy barrier* and its maximum height indicates how resistant the system is to effective coagulation.

In order to agglomerate, two particles on a collision course must have sufficient kinetic energy (due to their speed and mass) to *jump over* this barrier. Once the energy barrier is cleared, the net interaction energy is all attractive. No further repulsive areas are encountered and as a result the particles agglomerate. This attractive region is often referred to as an *energy trap* since the colloids can be considered to be trapped together by the van der Waals forces.

Destabilization of colloids

For effective coagulation, the energy barrier should be lowered or completely removed so that the net interaction is always attractive. This can be accomplished by either compressing the double layer or reducing the surface charge.

Double layer compression involves adding salts to the system. As the ionic concentration increases, the double layer and the repulsion energy curves are compressed until there is no longer an energy barrier. Particle agglomeration occurs rapidly under these conditions because the colloids can just about fall into the van der Waals "trap" without having to surmount an energy barrier.

The other option charge neutralization is achieved by using coagulants and polyelectrolytes. It is a practical way to lower the DLVO energy barrier and form stable flocs. Charge neutralization involves adsorption of a positively charged coagulant on the surface of the colloid. This charged surface coating neutralizes the negative charge of the colloid, resulting in a near zero net charge. Neutralization is the key to optimizing treatment before sedimentation.

Coagulation & Flocculation

Coagulation takes place when the DLVO energy barrier is effectively eliminated; this lowering of the energy barrier is also referred to as *destabilization*.

Flocculation refers to the successful collisions that occur when the destabilized particles are driven toward each other by the hydraulic shear forces in the rapid mix and flocculation basins. Agglomerates of a few colloids quickly bridge together to form micro-flocs which in turn gather into visible floc masses.

Coagulation and flocculation can be caused by any of the following

- Double layer compression
- Charge neutralization
- Bridging
- Colloid entrapment

Settling / Clarification

Sedimentation is the process by which solids are removed from the water by means of gravity separation. In the sedimentation process, the water passes through a basin in which relatively quiescent conditions prevail. Under these conditions, the floc particles formed during flocculation settle to the bottom of the basin while the "clear" water passes out of the basin over an effluent baffle or weir. The solids collected on the basin bottom are removed by a mechanical "sludge collection" device. The sludge collection device scrapes the solids (sludge) to a collection point within the basin from which it is pumped directly to disposal or to a sludge treatment process.

Conventional sedimentation typically involves one or more basins. These "clarifiers" (Figure 2) are relatively large open tanks, either circular or rectangular in shape. In properly designed clarifiers, velocity currents are reduced to the point where gravity is the predominant force acting on the water/solids suspension. Under this condition, the difference in specific gravity between the water and the solids particles causes the solids particles to settle to the bottom of the basin.

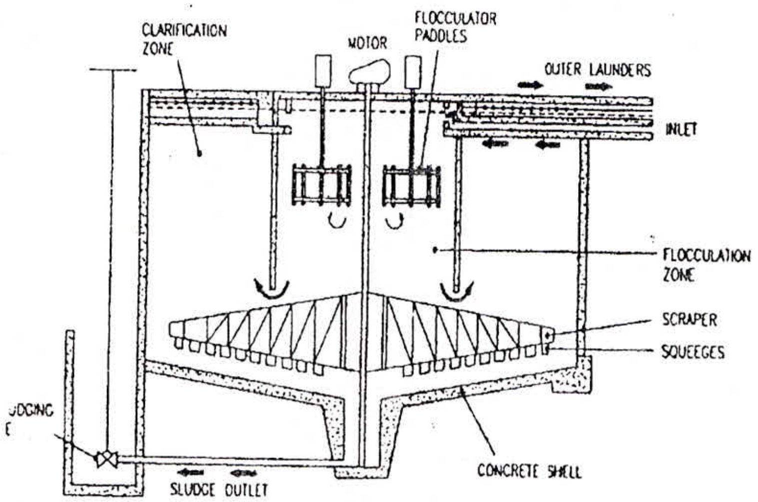

Figure 2: Cross sectional view of clariflocculator

High rate sedimentation is similar to conventional sedimentation except that the sedimentation basin has been modified through the addition of some mechanical or other device to aid in the settling process. These mechanical devices typically consist of plates or tubes intended to reduce the distance the solids particles must settle through the water before they reach the bottom of the basin and can be removed. Figure 3 illustrates a plate settler used for high rate sedimentation.

Another high rate clarification process employs an "adsorption clarifier" and is designed to provide flocculation and clarifications within a single process. These clarifiers consist of a basin filled with adsorption media, generally small particles of either plastic or rock, about the size of pea gravel. As the water passes through the media, hydraulic mixing promotes flocculation and the flocculated particles adhere to the surface of the media particles. The media is cleaned periodically using an air or air and water backwash process to remove the solids.

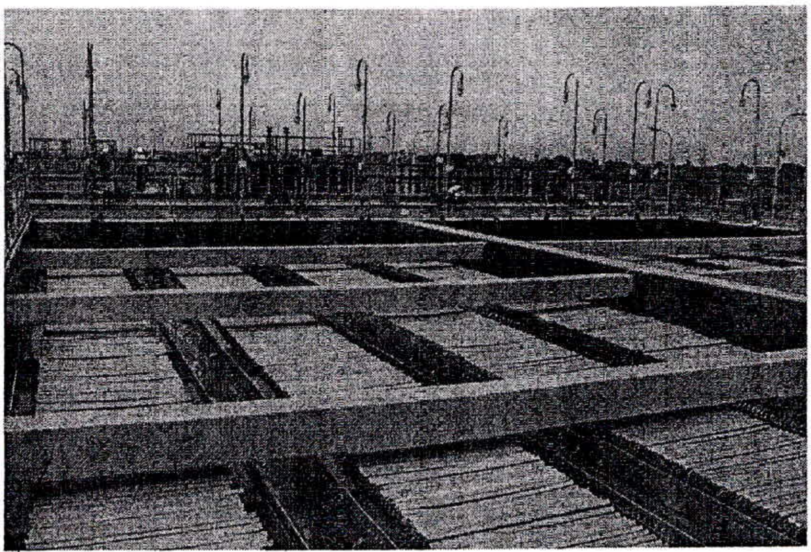

Figure 3: Lamella Clarifier

Solids Contact clarifiers represent an entirely different approach to high rate clarification. They consist of a basin similar to that used for a conventional clarifier but with a sludge recycle system to promote development of a dense sludge blanket. As the water enters the bottom of the basin and passes upward through the sludge blanket, the flocculated solids in the blanket tend to contact and capture or adsorb the solids from the water.

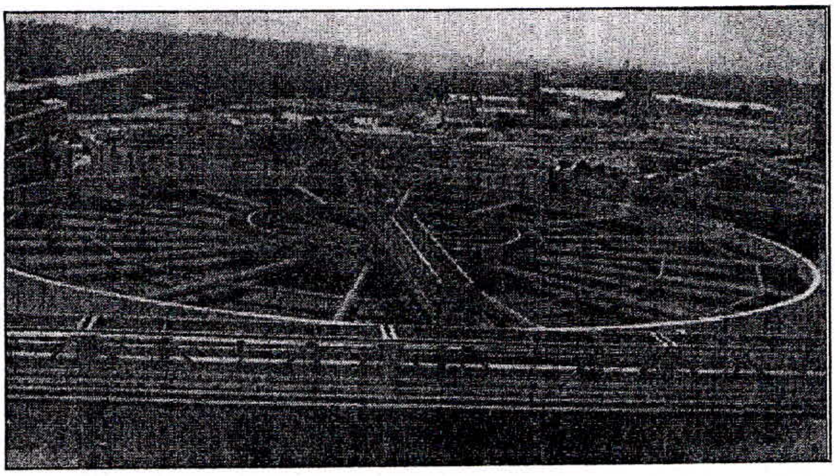

Figure 4: Aerial view of solids contact clarifier

Filtration

There are many types of filters reported in literature. Based on the most popularly used type of filters, these can be classified as shown below-

Gravity filters

Gravity filters are operated under gravity using hydraulic head available and are usually open to atmospheric. Gravity filters are most suited for handling large flow rates. Media used is typically riverbed quality sand and the filter produces filtered water with extremely low turbidity of less than 1 NTU. The filter is backwashed by reversal of flow once the pressure drop exceeds the pre set value. Filtration rate is restricted to less than 5m/h.

a) **Conventional gravity filters -** Conventional Gravity Filters are units, which are used for filtering gravity flows of water, and which incorporate a nest of valves for the operation of the different functions of filtering, backwashing and rinsing. These units may be made of concrete, steel, or wood, but concrete is the material that is almost universally employed. Also, the rectangular form is the one that is most widely used, because, in that way, the walls of the inner units in any one battery can be made common to one another. Their application is generally limited to the municipal treatment field where high flow rates of water must be treated. The filter effluent water in such a case is usually pretreated in a coagulation and/ or settling basin.

   Based on the filter media used, gravity sand filters can be classified into single media or multimedia filters. In multimedia filters, top layer of lower specific gravity media such as anthracite or bituminous coal or crushed coconut shell with higher effective size (0.85 to 1.6 mm) is used. As the specific gravity of these media is lower (around 1.4), settling velocity of these media is lower and always form top layer over sand media. As the pore size of this top layer is more, they remove coarse particles and also act as flocculating chambers and aid in flocculation of particles and their removal. The basic principle in designing the dual media bed is to have coal as coarse as is consistent with solid removal to prevent surface blinding but to have the sand as fine as possible to provide maximum solid removal with maximum filtration rates.

b) **Automatic valveless gravity filters (AVGF) -** AVGF operates automatically on the head loss principle. This is generally accepted as being the most accurate control besides eliminating the need for continuous analysis of filtrate turbidity which is seldom practical. The head loss at which the AVGF initiates backwashing is determined by the height of the inverted U turn of the top of the backwash pipe. The level of water in this pipe is proportional to the head loss across the filter.

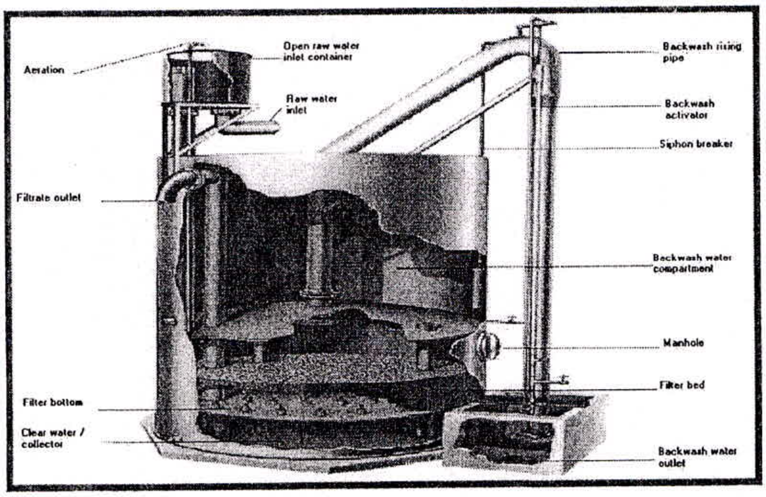

Figure 2: Cross sectional view of AVGF

c) **Continuous Sand (DynaSand) Filters** - DynaSand filter operates continuously and does not require to be stopped for backwash. Recycling the sand internally continuously cleans the filter media. Water to be filtered enters at the bottom, flows upward through a set of riser tubes and is evenly distributed into the sand bed through a distribution hood. The influent moves upward through the downward moving sand with the solids getting trapped in the sand. Filtered water exits from the sand bed, overflows a weir and is discharged from the filter.

Simultaneously, the sand is drawn downward into the suction of an air lift pump. The sand, dirt and water are transported upward through the pipe to the collection vessel in the upper part of the filter. Sand gets washed, is rinsed and clean sand falls back to the surface of the filter bed. The dirty liquid is discharged through the wash water outlet

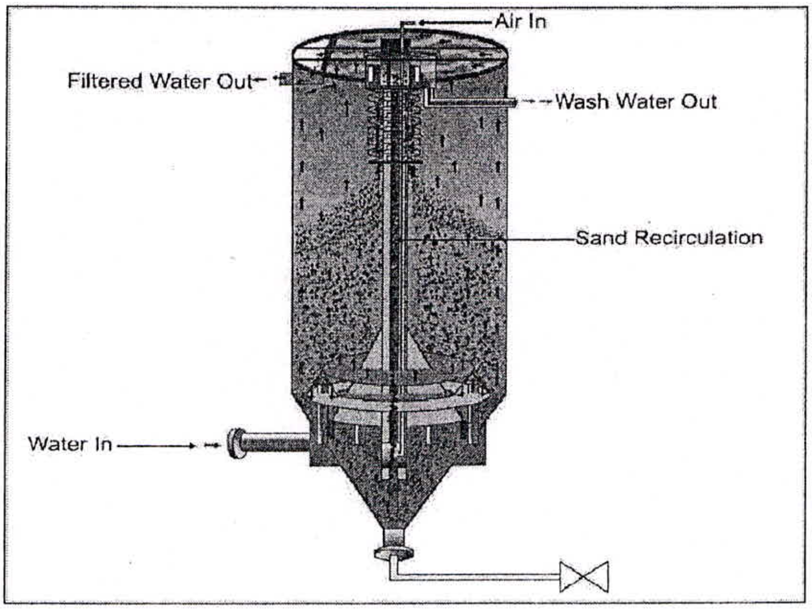

Figure 3: Cross sectional view of Continuous Sand Filter

Pressure Sand Filters

Unlike gravity filters, pressure filters require high pressure to drive water through the filter bed. A typical pressure filter consists of a pressure vessel (vertical or horizontal) fitted with a set of frontal pipe work and valves, filter media supported by layers of graded under bed consisting of pebbles and silex, a top distributor to distribute the incoming water uniformly throughout the cross section of the filter, and an under drain system to collect filtered water.

Raw water flows downwards through the filter bed and as the suspended matter- which has usually been treated by addition of a coagulant like alum- is retained on the sand surface and between the sand grains immediately below the surface. There is steady rise in the loss of head as the filtration process continues and the flow reduces once the pressure drop across the filter is excessive.

The filter is now taken out of service and cleaning of the filter is effected by flow reversal. To assist in cleaning the bed, the backwash operation is often preceded by air agitation through the under drain system. The process of air scouring agitates the sand with a scrubbing action, which loosens the intercepted particles. The filter is now ready to be put back into service.

a) **Single media and single grade filters -** In this type of filters, fine sand of single grade is used. The filtration is mainly limited to top surface of few centimeters. The flow rate in this type of filter is usually low (10 to 12 m/h) but it gives good treated water quality upto 1 NTU.

b) **Multigrade filters -** Multigrade filter is a depth filter that makes use of coarse and fine media mixed together in a fixed proportion. This arrangement produces a filter bed with adequate pore dimensions for retaining both large and small suspended particles. This filter performs at a substantially higher specific flow rate (15-30 m/h) than single grade filters.

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